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ABSTRACT

This activity guide for teachers interested in using the intense interest many children have in space exploration as a launching point for exciting hands-on learning opportunities begins with brief discussions of the space environment, the history of spacewalking, the Space Shuttle spacesuit, and working in space. These are followed by a series of activities that enable students to explore the space environment as well as the science and technology behind the functions of spacesuits. The activities are not rated for specific grade levels because they can be adapted for students of many ages. A chart on curriculum application is designed to help teachers incorporate activities into various subject areas. Activities and related student projects make use of inexpensive and easy-to-find materials and tools. Activities are arranged into four basic units including: (1) investigating the space environment; (2) dressing for spacewalking; (3) moving and working in space; and (4) exploring the surface of Mars. Contains 17 references and 25 resources. (LZ)

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ED 381 392

SUITED FOR SPACEWALKING

TEACHER'S GUIDE WITH ACTIVITIES FOR PHYSICAL AND LIFE SCIENCE

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About the Cover

Gemini-Titan 4 EVA View (1965) *- Astronaut Edward H. White II, floats in space outside of the Gemini-4 spacecraft. White was the first Gemini astronaut to leave his vehicle, tumbling and rolling in space for 21 minutes. He is secured to the spacecraft by an umbilical line and a tether line, both wrapped in gold tape to form one cord. In his right hand he carries a Hand-Held Self-Maneuvering Unit which allows him to control his movements in space.*

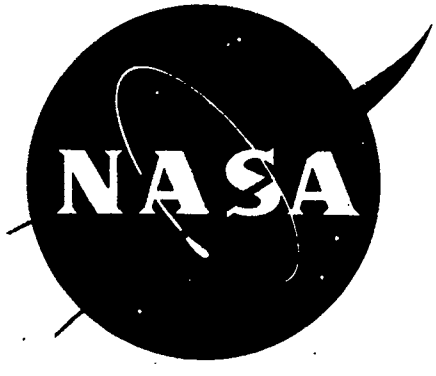
Skylab 3 EVA View (1973) *- Astronaut Owen K. Garriott is engaged in an EVA on the Skylab space station cluster in Earth orbit. Skylab spacesuits remained attached to the station by an umbilical tether that supplied oxygen and cooling water. A life-support assembly was worn on the chest and emergency oxygen was attached to the right upper leg.*

Apollo 11 EVA View (1969) *- Astronaut Edwin E. Aldrin, Jr. descends the steps of the Lunar Module ladder as he prepares to become the second person to walk on the moon. Apollo spacesuits were tetherless, providing a self-contained life support system to allow sample collection and operation of scientific equipment at great distances from the landing site.*

STS-61 EVA View (1993) *- This image captures Astronaut Kathryn C. Thornton on her first STS-61 extravehicular activity (EVA) session servicing the* Hubble Space Telescope. *Thornton wears a spacesuit designed solely for EVA. In past programs spacesuits, had to serve as backup systems for cabin pressure failure, possible ejections during launches, the microgravity environment, and during liftoff and reentry. Shuttle suits are only worn during EVAs, at other times, crewmembers wear comfortable shirts and slacks, or coveralls.*

Suited for Spacewalking

Teacher's Guide With Activities for Physical and Life Science



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Introduction

Spacewalking has captured the imagination of generations of children and adults since science-fiction authors first placed their characters on the Moon. But true spacewalking did not actually begin until the mid 1960s with the exploits of Alexei A. Leonov of the Soviet Union and Edward H. White II of the United States. Since those first tentative probings outside a space capsule, astronauts and cosmonauts have logged thousands of hours on extravehicular activities, and some have even walked on the surface of the Moon. The stories of their missions in space are fascinating, but just as interesting is the spacesuit technology that made it possible for them to "walk" in space.

This publication is an activity guide for teachers interested in using the intense interest many children have in space exploration as a launching point for exciting hands-on learning opportunities. The guide begins with brief discussions of the space environment, the history of spacewalking, the Space Shuttle spacesuit, and working in space. These are followed by a series of activities that enable children to explore the space environment as well as the science and technology behind the functions of spacesuits. The activities are not rated for specific grade levels because they can be adapted for students of many ages. The chart on curriculum application at the back of the book is designed to help teachers incorporate activities into various subject areas.

Measurement

This activity guide makes exclusive use of the metric system for measurement. If English-system equivalents are desired, a table of conversion factors can be found in many dictionaries and science textbooks. The metric unit for pressure may be unfamiliar to readers, and an English-system conversion factor for this unit may not appear in some tables. The metric unit for pressure is the pascal. A pascal is equal to a force of one newton exerted over an area of one square meter. Because the pascal is a relatively small unit, the more convenient unit of kilopascal (1,000 pascals) is used here instead. To convert kilopascals to the English-system unit of pounds per square inch, divide by 6.895.

Earth and Space

Earth as seen by the crew of the Apollo 17 Moon mission.

If we loosely define an astronaut as someone who travels through space, then everyone is an astronaut. Even though we may be standing still on the surface of Earth, we are actually traveling through space. Indeed, our planet may be thought of as a spaceship on a never-ending voyage. As "astronauts" traveling through space on the surface of Earth, we take for granted the complex environment that sustains life. Earth's gravitational attraction holds a dense atmosphere of nitrogen, oxygen, carbon dioxide, and water vapor in a thick envelope surrounding Earth's entire surface. The weight of this atmosphere exerts pressure, and its movements distribute heat from the Sun to balance global temperatures. Its density filters out harmful radiations and disintegrates all but the largest meteoroids. Earth's atmosphere is a shell that protects and sustains the life forms that have evolved on its surface. Without the atmosphere's protection, life as presently known would not be possible.

When Earth astronauts leave the surface of their planet and travel into space, they must carry some of their environment with them. It must be contained in a physical shell because their body masses are too small to hold it in place by gravitational attraction alone. The shell that is used is called a spacecraft—a rigid collection of metal, glass, and plastic. Though far simpler in function than Earth's, a spacecraft's environment serves well for short missions lasting a few days or weeks. On some flights, the shell is deliberately opened and the astronauts pass through an airlock to venture outside. When doing so, they must still be protected by a smaller and very specialized version of their spacecraft called the Extravehicular Mobility Unit (EMU). This smaller spacecraft is composed of a spacesuit with a life-support system. It differs from the first spacecraft, or mother ship, in its anthropomorphic (human) shape and its flexibility. Astronauts wearing EMUs need to be able to move arms, hands, and legs to perform an array of tasks in space. They must be able to operate many types of scientific apparatus, collect samples, take pictures, assemble equipment and structures, pilot themselves about, and repair and service defective or worn-out satellites and other space hardware. The tasks of astronauts outside their mother ship are called extravehicular activities, or EVAs.

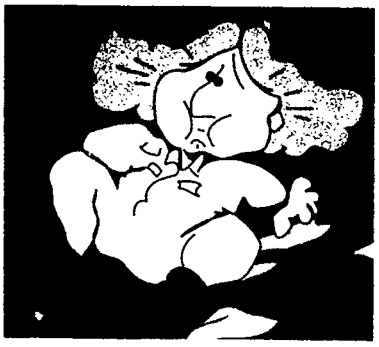
The Outer Space Environment

Outer space is just what its name implies. It is the space that surrounds the uppermost reaches of the atmosphere of Earth and all other objects in the universe. Although it is a void, outer space may be thought of as an environment.

Radiation and objects pass through it freely. An unprotected human or other living being placed in the outer space environment would perish in a few brief, agonizing moments.

The principal environmental characteristic of outer space is the vacuum, or nearly total absence of gas molecules. The gravitational attraction of large bodies in space, such as planets and stars, pulls gas molecules close to their surfaces, leaving the space between virtually empty. Some stray gas molecules are found between these bodies, but their density is so low that they can be thought of as practically nonexistent.

On Earth, the atmosphere exerts pressure in all directions. At sea level, that pressure is 101 kilopascals. In space, the pressure is nearly zero. With virtually no pressure from the outside, air inside an unprotected human's lungs would immediately rush out in the vacuum of space; dissolved gases in body fluids would expand, pushing solids and liquids apart. The skin would expand much like an inflating balloon. Bubbles would form in the bloodstream and render blood ineffective as a transporter of oxygen and nutrients to the body's cells. Furthermore, the sudden absence of external pressure balancing the internal pressure of body fluids and gases would rupture fragile tissues such as eardrums and capillaries. The net effect on the body would be swelling, tissue damage, and a deprivation of oxygen to the brain that would result in unconsciousness in less than 15 seconds.



The temperature range found in outer space provides a second major obstacle for humans. The sunlit side of objects in space at Earth's distance from the Sun can climb to over 120° Celsius while the shaded side can plummet to lower than minus 100° Celsius. Maintaining a comfortable temperature range becomes a significant problem.

Other environmental factors encountered in outer space include: microgravity, radiation of electrically charged particles from the Sun, ultraviolet radiation, and meteoroids. Meteoroids are very small bits of rock and metal left over from the formation of the solar system and from the collisions of comets and asteroids. Though usually small in mass, these particles travel at very high velocities and can easily penetrate human skin and thin metal. Equally dangerous is debris from previous space missions. A tiny paint chip, traveling at thousands of kilometers per hour, can do substantial damage.

Spacewalking History

The Extravehicular Mobility Unit worn during spacewalks by NASA's Space Shuttle astronauts represents more than 50 years of development and testing of pressure suits in the U.S., France, Italy, Germany, and other countries. It all began with high-altitude flyers, and one of the first was an American, Wiley Post. Post was an aviation pioneer of the 1930s who was seeking to break high-altitude and speed records. Post, as well as others, knew that protection against low pressure was essential. Through experience, aviators had learned that Earth's atmosphere thins out with altitude.

At 5,500 meters, air is only one-half as dense as it is at sea level. At 12,200 meters, the pressure is so low and the amount of oxygen present is so small that most living things perish. For Wiley Post to achieve the altitude records he sought, he needed protection. (Pressurized aircraft cabins had not yet been developed.) Post's solution was a suit that could be pressurized by his airplane engine's supercharger.

First attempts at building a pressure suit failed, since the suit became rigid and immobile when pressurized. Post discovered he couldn't move inside the inflated suit, much less work airplane controls. A later version succeeded with the suit constructed already in a sitting position. This allowed Post to place his hands on the airplane controls and his feet on the rudder bars. Moving his arms and legs was difficult, but not impossible. To provide visibility, a viewing port was part of the rigid helmet placed over Post's head. The port was small, but a larger one was unnecessary because Post had only one good eye!

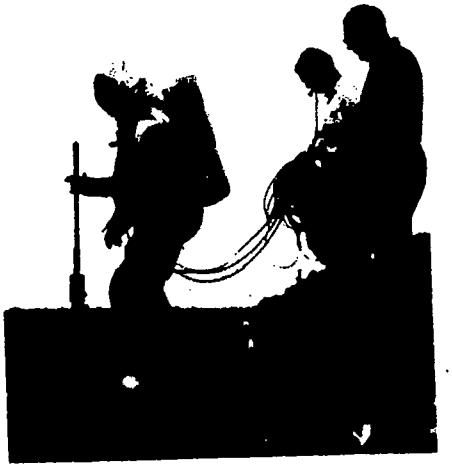
Aviation pioneer Wiley Post.

During the next 30 years, pressure suits evolved in many ways, and technical manufacturing help was gained from companies that made armor, diving suits, galoshes, and even girdles and corsets. Designers learned in their search for the perfect suit that it wasn't necessary to provide full sea-level pressure. A suit pressure of 24.13 kilopascals would suffice quite nicely if the wearer breathed pure oxygen. Supplying pure oxygen at this low pressure actually provides the breather with more oxygen than an unsuited person breathes at sea level. (Only one-fifth of the air at sea level is oxygen.)

Early spacesuit design.

Various techniques were used for constructing pressure garments. Some approaches employed a rigid layer with special joints of rings or cables or some other device to permit limb movements. Others used nonstretch fabrics—laced up corset fashion.

With the advent of pressurized aircraft cabins, comfort and mobility in the suit when it was unpressurized became prime objectives in suit design. The suit could then be inflated in the



Apollo spacesuit prototype undergoes testing on a simulated Moon walk.

event that the aircraft cabin lost pressure.

By the time NASA began the Mercury manned space flight program, the best full-pressure suit design consisted of an inner gas-bladder layer of neoprene-coated fabric and an outer restraint layer of aluminized nylon. The first layer retained pure oxygen at 34.5 kilopascals; the second layer prevented the first from expanding like a balloon. This second fabric restraint layer directed the oxygen pressure inward on the astronaut. The limbs of the suit did not bend in a hinge fashion as do human arms and legs. Instead, the fabric arms and legs bent in a gentle curve, which restricted movement. When the astronaut moved one of his arms, the bending creased or folded the fabric inward near the joints, decreasing the volume of the suit and increasing its total pressure slightly. Fortunately for the comfort of the Mercury astronauts, the Mercury suit was designed to serve only as a pressure backup if the spacecraft cabin decompressed. No Mercury capsule ever lost pressure during a mission, and the suits remained uninflated.

The six flights of the Mercury series were followed by ten flights in the Gemini program. Suit designers were faced with new problems. Not only would a Gemini suit have to serve as a pressure backup to the spacecraft cabin, but also as an escape suit if ejection seats had to be fired for an aborted launch and as an EMU for extravehicular activity. To increase mobility and comfort of the suit for long-term wear, designers departed from the Mercury suit concept. Instead of fabric joints, they chose a construction that employed a bladder restrained by a net. The bladder was an anthropomorphically shaped layer of neoprene-coated nylon. That was covered in turn with a layer of Teflon-coated nylon netting. The netting, slightly smaller than the pressure bladder, limited inflation of the bladder and retained the pressure load in much the same way automobile tires retained the load in inner tubes in the days before tubeless tires. The new spacesuit featured improved mobility in the shoulders and arms and was more comfortable when worn unpressurized during space flights lasting as long as 14 days.

Edward H. White II's historic spacewalk.

Project Mercury astronauts. (Front row, left to right) Walter M. Schirra, Jr., Donald K. Slayton, John H. Glenn, Jr., M. Scott Carpenter. (Back row, left to right) Alan B. Shepard, Jr., Virgil I. Grissom, L. Gordon Cooper, Jr.

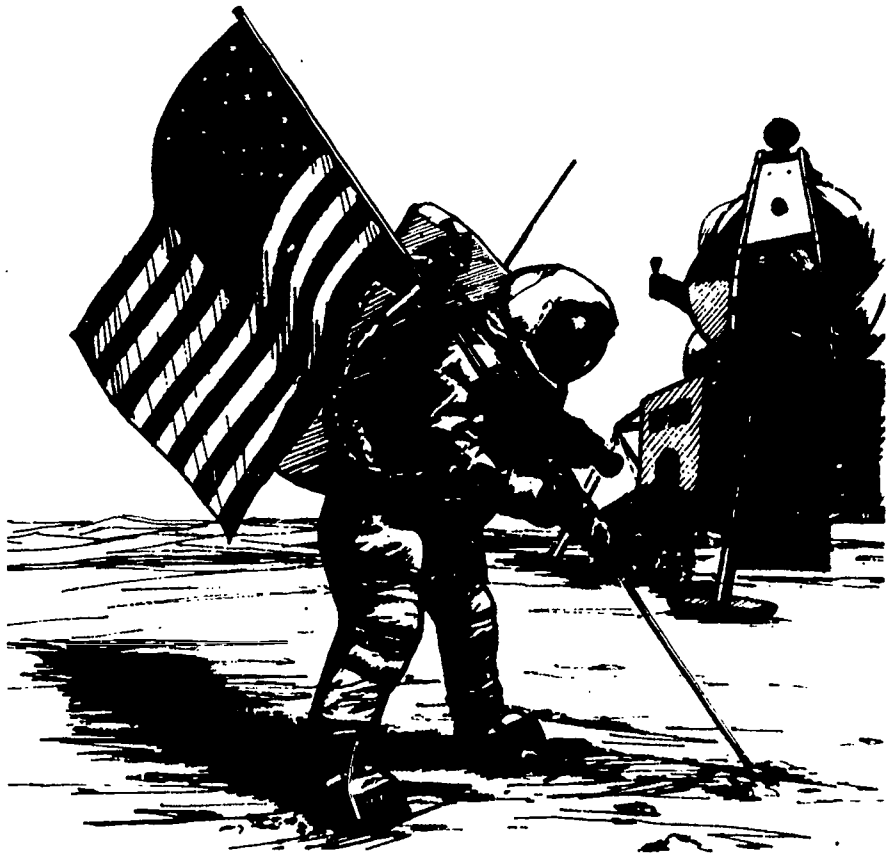
The first Gemini astronaut to leave his vehicle ("go EVA") was Edward White. White exited from the Gemini 4 space capsule on June 3, 1965—just a few months after Leonov made the first Soviet spacewalk. For a half hour White tumbled and rolled in space, connected to the capsule only by an oxygen-feed hose that

served secondary functions as a tether line and a communication link with the capsule. Although the term "spacewalk" was coined for the Gemini program, no actual walking was involved. On his spacewalk, White used a small hand-held propulsion gun for maneuvering in space. When he pulled a trigger, the gun released jets of nitrogen that propelled him in the opposite direction. It was the first personal maneuvering unit used in space.

Upon completion of the Gemini program, NASA astronauts had logged nearly 12 additional hours of EVA experience. Approximately one-half of that time was spent merely standing up through the open hatch.

One of the most important lessons learned during the Gemini program was that EVAs were not as simple as they looked. Moving around in space required a great deal of work. The work could be lessened, however, by extensive training on Earth. The most effective training took place underwater. Wearing specially weighted spacesuits while in a deep tank of water gave later Gemini crewmembers adequate practice in maneuvers they would soon perform in space. It was also learned that a better method of cooling the astronaut was required. The gas cooling-system could not remove heat and moisture as rapidly as the astronaut produced them, and the inside of the helmet visor quickly fogged over, making it difficult to see.

Following Gemini, the Apollo program added a new dimension in spacesuit design because actual spacewalks (on the surface of the Moon) were now to occur for the first time. As with Mercury and Gemini space garments, Apollo suits had to serve as a backup pressure system to the space capsule. Besides allowing flexibility in the shoulder and arm areas, they also had to permit movements of the legs and waist. Astronauts needed to be able to bend and stoop to pick up samples on the Moon. Suits had to function both in microgravity and in the one-sixth gravity of the Moon's surface. Furthermore, when walking on the Moon, Apollo astronauts needed the flexibility to roam freely without dragging a cumbersome combination oxygen line and tether. A self-contained portable life-support system was needed.



The Apollo spacesuit began with a garment that used water as a coolant. The garment, similar to long johns but laced with a network of thin-walled plastic tubing, circulated cooling water around the astronaut to prevent overheating. On top of this layer was the pressure garment assembly. The innermost layer of this assembly was a comfort layer of lightweight nylon with fabric ventilation ducts. This was followed by a multilayered outer suit. The innermost layer of this garment was a neoprene-coated nylon bladder surrounded by a nylon restraint layer. Improved mobility was achieved by bellows-like joints of formed rubber with built-in restraint cables at the waist, elbows, shoulders, wrist, knees, and ankles. Next followed five layers of aluminized Mylar for heat protection, mixed with four spacing layers of nonwoven Dacron. Outside of that were two layers of Kapton and beta marquisette for additional thermal protection, and these were covered with a nonflammable and abrasion-protective layer of Teflon-coated filament beta cloth. The outermost layer of the suit was white Teflon cloth. The last two layers were flame resistant. In total, the suit layers provided pressure, served as a protection against heat and cold, and protected the wearer against micrometeoroid impacts and the wear and tear of walking on the Moon.

Capping off the suit was a communications headset and a clear polycarbonate-plastic pressure helmet. Slipped over the top of the helmet was an assembly consisting of sun-filtering visors and adjustable blinders for sunlight protection. The final items of the Apollo spacesuit were custom-sized gloves with molded silicone-rubber fingertips that provided some degree of fingertip sensitivity in handling equipment, lunar protective boots, and a portable life-support system.

The life-support system, a backpack unit, provided oxygen for breathing and pressurization, water for cooling, and radio communications for lunar surface excursions lasting up to eight hours. Furthermore, back inside the lunar lander the life-support system could be recharged for additional Moon walks.

During the Apollo program, 12 astronauts spent a total of 161 hours of EVA on the Moon's surface. An additional four hours of EVA were spent in microgravity while the astronauts were in transit from the Moon to Earth. During those four hours, a single astronaut, the command module pilot, left the capsule to retrieve photographic film. There was no need for the portable life-support system away from the Moon, as those astronauts were connected to the spacecraft by umbilical tether lines supplying them with oxygen.

NASA's next experience with EVAs came during the Skylab program and convincingly demonstrated the need for astronauts on a spacecraft. Space-suited Skylab astronauts literally saved the Skylab program.

Skylab was NASA's first space station. It

Astronaut Owen Garriott performs maintenance activities for the Skylab space station.

was launched in 1973, six months after the last Apollo Moon landing. Trouble developed during the launch when a micrometeoroid shield ripped away from the station's outer surface. This mishap triggered the premature deployment of two of the six solar panels, resulting in one being ripped away by atmospheric friction. The second was jammed in a partially opened position by a piece of bent metal. In orbit, Skylab received insufficient electrical power from the remaining solar panels: the station was overheating because of the missing shield. Instead of scrapping the mission, NASA assigned the first three-astronaut crew the task of repairing the crippled station. While still on board the Apollo command module, Paul Weitz

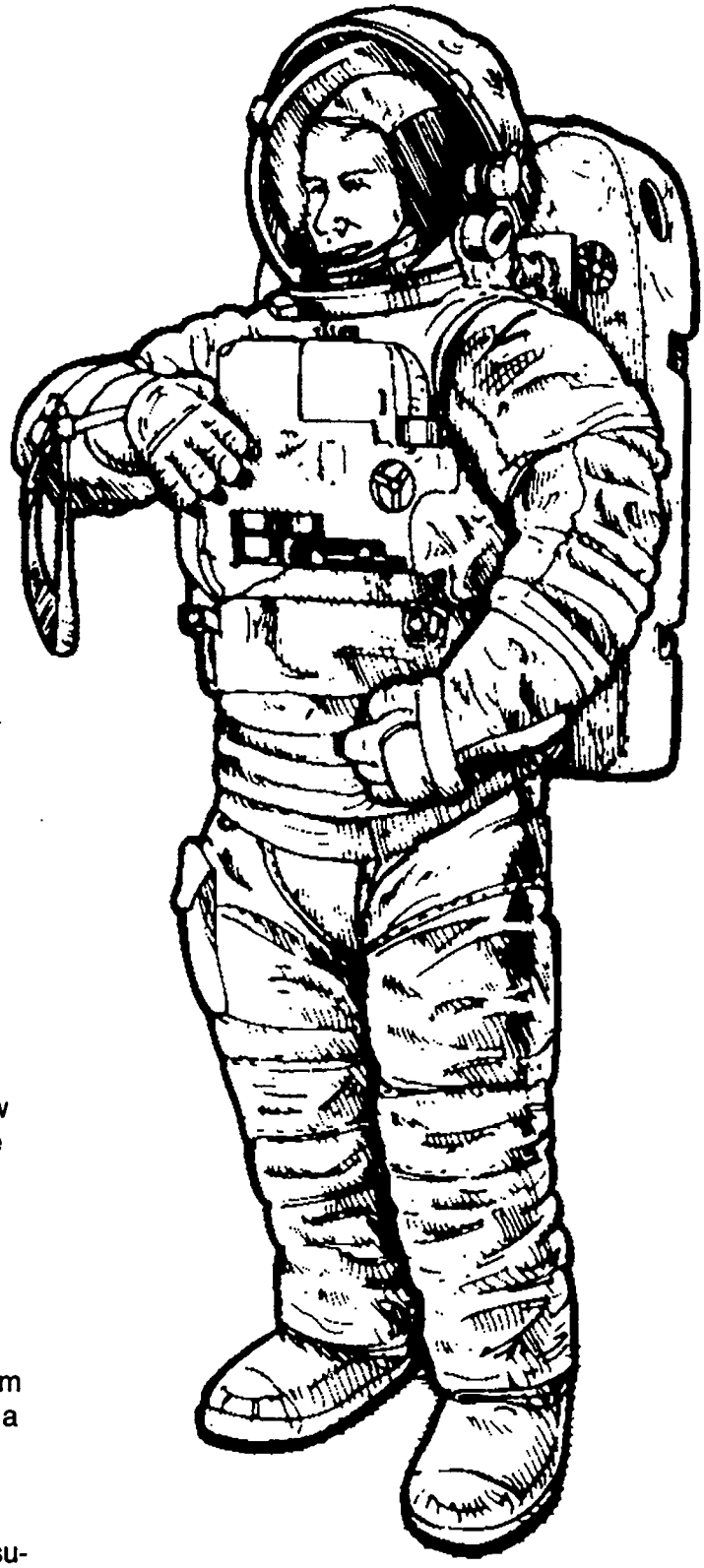
unsuccessfully attempted to free the jammed solar panel as he extended himself through the open side hatch. On board Skylab, the crew poked an umbrella-like portable heat shield through the scientific airlock to cover the area where the original shield was torn away. Later, on an EVA, the metal holding the jammed solar arrays was cut, and the panel was freed to open. During an EVA by the second Skylab crew, an additional portable heat shield was erected over the first.

The Skylab EMU was a simplified version of the Apollo Moon suits. There was no need for the portable life-support system, because the crewmember was attached to the station by an umbilical tether that supplied oxygen and cooling water. An astronaut life-support assembly, consisting of a pressure-control unit and an attachment for the tether, was worn on the chest, and an emergency oxygen package containing two supply bottles was attached to the right upper leg. A simplified visor assembly was used over the pressure helmet. Lunar protective boots were not needed. Skylab astronauts logged 17.5 hours of planned EVA for film and experiment retrieval and 65 hours of unplanned EVA for station repairs.

The Space Shuttle EMU

The Space Shuttle has opened an entirely new era in space travel. Launched as a rocket, the Shuttle operates in space as a spacecraft and returns to Earth as an airplane. Both the orbiter and its solid rocket boosters are reusable. Only the external tank is expended and replaced after each mission. The orbiter's payload bay, 18.3 meters long and 4.6 meters in diameter, with its remote manipulator system (RMS), or mechanical arm, makes the Shuttle a versatile space transportation system.

A new EMU enhances the Shuttle's overall capabilities. Like the spacecraft itself, the new Shuttle EMU is reusable. The spacesuits used in previous manned space flight programs were custom built to each astronaut's body size. In the Apollo program, for example, each astronaut had three custom suits—one for flight, one for training, and one for flight backup.



Shuttle suits, however, are tailored from a stock of standard-size parts to fit astronauts with a wide range of measurements.

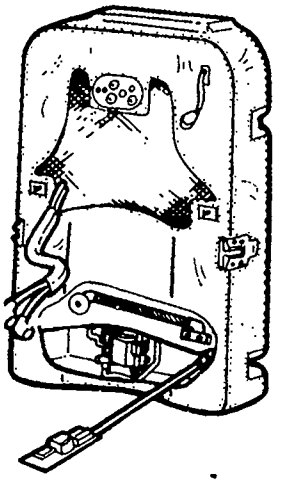
In constructing the new Shuttle spacesuit, developers were able to concentrate all their designs toward a single function—going EVA. Suits from earlier manned space flight programs had to serve multiple functions. They had to provide backup pressure in case of cabin pressure failure and protection if ejection became necessary during launch (Gemini missions). They also had to provide an environment for EVA in microgravity and while walking on the Moon (Apollo missions). Suits were worn during lift off and reentry and had to be comfortable under the high-g forces experienced during acceleration and deceleration. Shuttle suits are worn only when it is time to venture outside the orbiter cabin. At other times, crewmembers wear comfortable shirts and slacks, or coveralls.

Many Layers

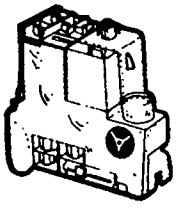
The Shuttle EMU has 12 layers to protect astronauts on EVAs. The two inner layers comprise the liquid-cooling-and-ventilation garment. It is made of spandex fabric and plastic tubing. Next comes the pressure bladder layer of urethane-coated nylon and fabric layer of pressure-restraining Dacron. This is followed by a seven-layer thermal micrometeoroid garment of aluminized Mylar, laminated with Dacron scrim topped with a single-layer fabric combination of Gortex, Kevlar, and Nomex materials.

Shuttle EMU End Items

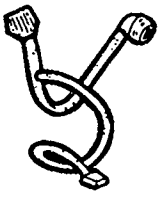
The Shuttle EMU consists of 19 separate items. Fully assembled, the Shuttle EMU becomes a nearly complete short-term spacecraft for one person. It provides pressure, thermal and micrometeoroid protection, oxygen, cooling water, drinking water, food, waste collection, (including carbon dioxide removal), electrical power, and communications. The EMU lacks only maneuvering capability, but this capability can be added by fitting a gas-jet-propelled Manned Maneuvering Unit (MMU) over the EMU's primary life-support system. On Earth, the suit and all its parts, fully assembled but without the MMU, weighs about 113 kilograms. Orbiting above Earth it has no weight at all. It does, however, retain its mass in space, which is felt as resistance to a change in motion.



1. Primary Life-Support System (PLSS)
A self-contained backpack unit containing an oxygen supply, carbon-dioxide-removal equipment, caution and warning system, electrical power, water-cooling equipment, ventilating fan, machinery, and radio.

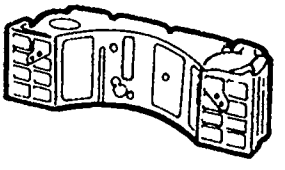


2. Displays and Control Module (DCM)
Chest-mounted control module containing all controls, a digital display, and the external liquid, gas, and electrical interfaces. The DCM also has the primary purge valve for use with the Secondary Oxygen Pack.



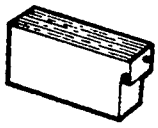
3. EMU Electrical Harness (EEH)
A harness worn inside the suit to provide bioinstrumentation and communications connections to the PLSS.

4. Secondary Oxygen Pack (SOP)
Two oxygen tanks with a 30-minute emergency supply, valve, and regulators. The SOP is attached to the base of the PLSS. The SOP can be removed from the PLSS for ease of maintenance.



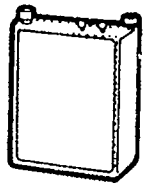
5. Service and Cooling Umbilical (SCU)
Connects the orbiter airlock support system to the EMU to support the astronaut before EVA and to provide in-orbit recharge capability for the PLSS. The SCU contains lines for power, communications, oxygen and water recharge, and water drainage. The SCU con-

serves PLSS consumables during EVA preparation.

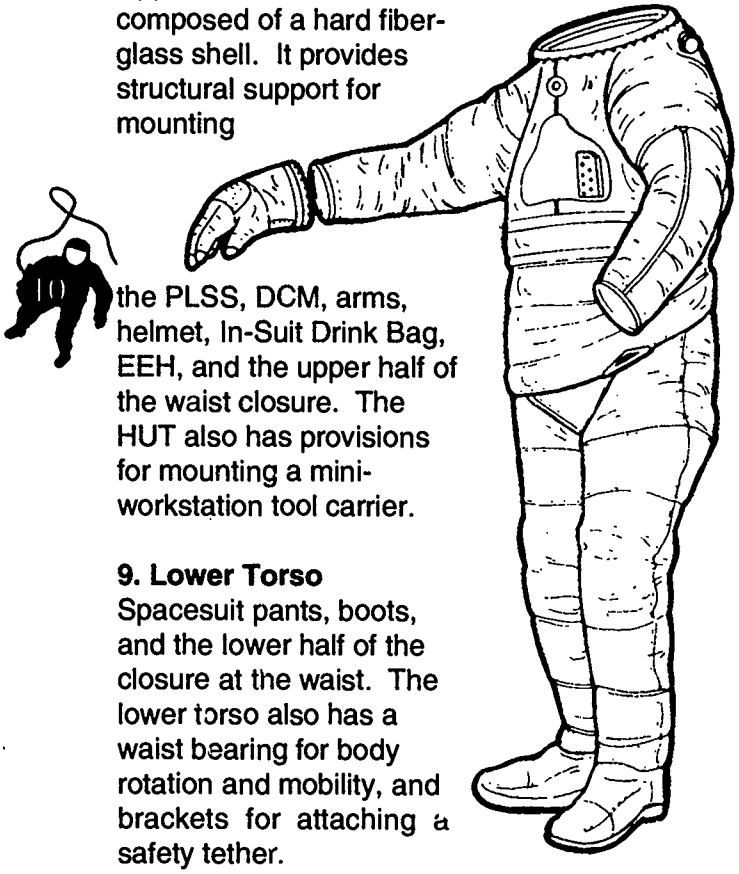


6. Battery
Supplies electrical power for the EMU during EVA. The battery is rechargeable in orbit.

7. Contaminant Control Cartridge (CCC)
Cleanses suit atmosphere of contaminants with an integrated system of lithium hydroxide, activated charcoal, and a filter contained in one unit. The CCC is replaceable in orbit.



8. Hard Upper Torso (HUT)
Upper torso of the suit, composed of a hard fiberglass shell. It provides structural support for mounting



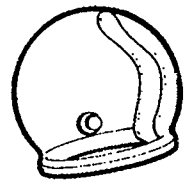
the PLSS, DCM, arms, helmet, In-Suit Drink Bag, EEH, and the upper half of the waist closure. The HUT also has provisions for mounting a mini-workstation tool carrier.

9. Lower Torso
Spacesuit pants, boots, and the lower half of the closure at the waist. The lower torso also has a waist bearing for body rotation and mobility, and brackets for attaching a safety tether.

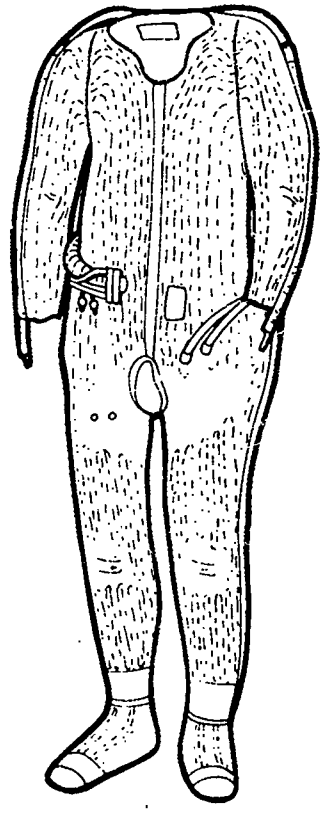
10. Arms (left and right)
Shoulder joint and armscye (shoulder) bearing, upper arm bearings, elbow joint, and glove-attaching closure.

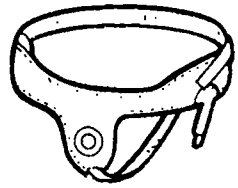
11. EVA Gloves (left and right)
Wrist bearing and disconnect, wrist joint, and fingers. One glove has a wristwatch sewn onto the outer layer. The gloves have tethers for restraining small tools and equipment. Generally, crewmembers also wear thin fabric comfort gloves with knitted wristlets under the EVA gloves.

12. Helmet
Plastic pressure bubble with neck disconnect ring and ventilation distribution pad. The helmet has a backup purge valve for use with the secondary oxygen pack to remove expired carbon dioxide.



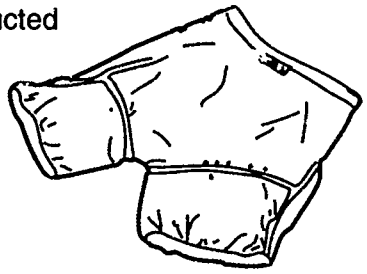
13. Liquid Cooling-and-Ventilation Garment (LCVG)
Long underwear-like garment worn inside the pressure layer. It has liquid cooling tubes, gas ventilation ducting, and multiple water and gas connectors for attachment to the PLSS via the HUT.



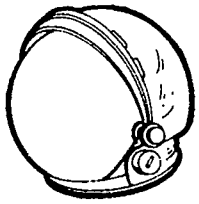


14. Urine Collection Device (UCD)
Urine collection device for male crewmembers consisting of a roll-on cuff and storage bag. The UCD is discarded after use.

15. Disposable Absorption and Containment Trunk (DACT)
Urine-collection garment for female crewmembers consisting of a pair of shorts constructed from five layers of chemically treated absorbent nonwoven fibrous materials. The DACT is discarded after use.

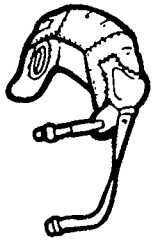


16. Extravehicular Visor Assembly (EVA)
Assembly containing a metallic-gold-covered Sun-filtering visor, a clear thermal impact-protective visor, and adjustable blinders that attach over the helmet. In addition, four small "head lamps" are mounted on the assembly; a TV camera-transmitter may also be added.

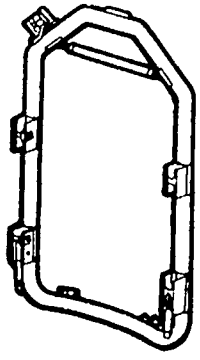


17. In-Suit Drink Bag (IDB)
Plastic water-filled pouch mounted inside the HUT. A tube projecting into the helmet works like a straw.

18. Communications Carrier Assembly (CCA)
Fabric cap with built-in earphones and a microphone for use with the EMU radio.



19. Airlock Adapter Plate (AAP)
Fixture for mounting and storing the EMU inside the airlock and for use as an aid in donning the suit.



Putting On the EMU

Putting on a Shuttle EMU is a relatively simple operation that can be accomplished in a matter of about 15 minutes. However, the actual process of preparing to go EVA takes much longer. When working in the Shuttle cabin, crewmembers breathe a normal atmospheric mix of nitrogen and oxygen at 101 kilopascals. The suit's atmosphere is pure oxygen at 29.6 kilopascals. A rapid drop from the cabin pressure to the EMU pressure could result in a debilitating ailment that underwater divers sometimes experience—the bends. The bends, also known as caisson disease, are produced by the formation and expansion of nitrogen gas bubbles in the bloodstream when a person breathing a normal air mixture at sea-level pressure is exposed to a rapid drop in external pressure. The bends are characterized by severe pains in the joints, cramps, paralysis, and eventual death if not treated by gradual recompression. To prevent an occurrence of the bends, crewmembers intending to go EVA spend a period of time prebreathing pure oxygen. During that time, nitrogen gas in the bloodstream is replaced by pure oxygen.

Prebreathing begins when the crewmembers who plan to go EVA don the special launch and entry helmets. For one hour they are attached to the orbiter's oxygen supply system and breathe pure oxygen. With a long feeder hose, they can go about their business and initiate the next phase of prebreathing.

The atmospheric pressure of the entire orbiter cabin is depressed from the normal 101 kilopascals to 70.3 pascals while the percentage of oxygen is slightly increased. This step must take place at least 24 hours before the exit into space. By now, much of the dissolved nitrogen gas has been cleared from the EVA crewmembers, and they can remove their helmets. Later, when they don their spacesuits and seal the helmets, an additional 30 to 40 minutes of pure oxygen prebreathing takes place before the suits are lowered to their operating pressure of 29.6 kilopascals.

Most of the EMU-donning process takes place inside the airlock. The airlock is a cylindrical chamber located on the orbiter's middeck. One hatch leads from the middeck into the airlock, and a second hatch leads from the airlock out to the unpressurized payload bay.

Before entering the hatch, but following their initial prebreathing, the crewmembers put on the Urine Collection Device or Disposable Absorption and Containment Trunk. The urine collector for males is simply an adaptation of a device used by people who have kidney problems. It is a pouch with a roll-on connector cuff that can contain approximately one quart of liquid. The device for females consists of multilayered shorts that hold a highly absorptive powder. This system is also capable of containing about one quart of liquid.

Next comes the Liquid Cooling- and-Ventilation Garment. The LCVG has the general appearance of long underwear. It is a one-piece suit with a zippered front, made of stretchable spandex fabric laced with 91.5 meters of plastic tubing. When the EMU is completely assembled, cooling and ventilation become significant problems. Body heat, contaminant gases, and perspiration—all waste products—are contained by the insulation and pressure layers of the suit and must be removed. Cooling of the crewmember is accomplished by circulating chilled water through the tubes. Chilling the water is one of the functions of the Primary Life-Support System. The PLSS device for water cooling and the tubing system are designed to provide cooling for physical activity that generates up to 2 million joules of body heat per hour, a rate that is considered "extremely vigorous." (Approximately 160 joules are released by burning a piece of newsprint one centimeter square.) Ducting attached to the LCVG ventilates the suit by drawing ventilating oxygen and expired carbon dioxide from the suit's atmosphere into the PLSS for purification and recirculation. Body perspiration is also drawn away from the suit by the venting system. These ducts meet at a circular junction on the back of the LCVG after running along each arm and leg. Purified oxygen from the PLSS reenters the suit through another duct, mounted in the back of the helmet, that directs the flow over the astronaut's face to complete the circuit.

The EMU electrical harness is attached to the HUT and provides biomedical and communications hookups with the PLSS. The biomedical hookup monitors the heart rate of the crewmembers, and this information is radioed via a link with the orbiter to Mission Control on Earth. When the orbiter is over a ground tracking station, voice communications are also carried on this circuit.

Spacesuit technician prepares to put on the Space Shuttle EMU by first donning the Liquid Cooling-and-Ventilation garment.

Next, several simple tasks are performed. Antifog compound is rubbed on the inside of the helmet. A wrist mirror and a small spiral-bound 27-page checklist are put on the left arm of the upper torso. The wrist mirror was added to the suit because some of the knobs on the front of the displays and control module are out of the vision range of the crewmember. The mirror permits the knob settings to be read. (Setting numbers are written backwards for ease of reading in the mirror.)

Another task at this time is to insert a food bar and a water-filled In-Suit Drink Bag inside the front of the HUT. The food bar of compressed fruit, grain, and nuts is wrapped in edible rice paper, and its upper end extends into the helmet area near the crewmember's mouth. When hungry, the crewmember bites the bar and pulls it upward before breaking off a piece to chew. In that manner, a small piece of the bar remains extended into the helmet for the next bite. It is necessary to eat the entire bar at one time, because saliva quickly softens the protruding food bar, making it mushy and impossible to break off. The IDB is placed just above the bar. The bag is filled with up to 0.65 liters of water from the water supply in the orbiter's galley before the airlock is entered. A plastic tube and valve assembly extends up into the helmet so that the crewmember can take a drink whenever needed. Both the food bar and drink bag are held in place by Velcro attachments.

During EVAs, the crewmembers may need additional lighting to perform their tasks. A light-bar attachment (helmet-mounted light array) is placed above the helmet visor assembly. Small built-in flood lamps provide illumination to places that sunlight and the regular payload bay lights do not reach. The EVA light has its own battery system and can be augmented with a helmet-mountable television camera system with its own batteries and radio frequency transmitter. The camera's lens system is about the size of a postage stamp. Through this system, the crew remaining inside the orbiter and the mission controllers on Earth can get an astronaut's eye view of the EVA action. During complicated EVAs, viewers may be able to provide helpful advice for the tasks at hand.

Spacesuit technician "dives" into the upper torso of the Space Shuttle EMU.

Next, the Communications Carrier Assembly (CCA), or "Snoopy cap," is connected to the EMU electrical harness and left floating above the HUT. The CCA earphones and microphones are held by a fabric cap. After the crewmember dons the EMU, the cap is placed on the head and adjusted.

When the tasks preparatory to donning the suit are completed, the lower torso, or suit pants, is pulled on. The lower torso comes in various sizes to meet the varying size requirements of different astronauts. It features pants with boots and joints in the hip, knee, and ankle, and a metal body-seal closure for connecting to the mating half of the ring mounted on the hard upper torso. The lower torso's waist element also contains a large bearing.

This gives the crewmember mobility at the waist, permitting twisting motions when the feet are held in workstation foot restraints.

Joints for the lower and upper torsos represent an important advance over those of previous spacesuits. Earlier joint designs consisted of hard rings, bellows-like bends in the pressure bladder, or cable- and pulley-assisted fabric joints. The Shuttle EMU joints maintain nearly constant volume during bending. As the joints are bent, reductions in volume along the inner arc of the bend are equalized by increased volume along the outer arc of the bend.

Long before the upper half of the EMU is donned, the airlock's Service and Cooling Umbilical is plugged into the Displays and Control Module Panel on the front of the upper torso. Five connections within the umbilical provide the suit with cooling water, oxygen, and electrical power from the Shuttle itself. In this manner, the consumables stored in the Primary Life-Support System will be conserved during the lengthy prebreathing period. The SCU also is used for battery and consumable recharging between EVAs.

The airlock of the Shuttle orbiter is only 1.6 meters in diameter and 2.1 meters high on the inside. When two astronauts prepare to go EVA, the space inside the airlock becomes crowded. For storage purposes and as an aid in donning and doffing the EMU, each upper torso is mounted on airlock adapter plates. Adapter plates are brackets on the airlock wall for supporting the suits' upper torsos.

With the lower torso donned and the orbiter providing consumables to the suits, each crewmember "dives" with a squirming motion into the upper torso. To dive into it, the astronaut maneuvers under the body-seal ring of the upper torso and assumes a diving position with arms extended upward. Stretching out, while at the same time aligning arms with the suit arms, the crewmember slips into the upper torso. As two upper and lower body-seal closure rings are brought together, two connections are made. The first joins the cooling water-tubing and ventilation ducting of the LCVG to the Primary Life-Support System. The second connects the biomedical monitoring sensors to the EMU electrical harness that is connected to the PLSS. Both systems are turned on, and the crewmember then locks the two body-seal closure rings together, usually with the assistance of another crewmember who remains on board.

One of the most important features of the upper half of the suit is the HUT, or Hard Upper Torso. The HUT is a hard fiberglass shell under the fabric layers of the thermal-micrometeoroid garment. It is similar to the breast and back plates of a suit of armor. The HUT provides a rigid and controlled mounting surface for the Primary Life-Support System on the back and the Displays and Control Module on the front.

The Space Shuttle EMU.

In the past, during the Apollo Moon missions, donning suits was a very lengthy process because the life-support system of those suits was a separate item. Because the Apollo suits were worn during launch and landing and also as cabin-pressure backups, an HUT could not be used. It would have been much too uncomfortable to wear during the high accelerations and decelerations of lift-off and reentry. The life-support system had to be attached to the suit inside the lunar module. All connections between PLSS and the Apollo suit were made at that time and, with two astronauts working in cramped quarters, preparing for EVA was a difficult process. The Shuttle suit HUT eliminates that lengthy procedure because the PLSS is already attached. It also eliminates the exposed and vulnerable ventilation and life-support hoses of earlier EMU designs that could become snagged during EVA.

The last EMU gear to be donned includes eyeglasses if needed, the CCA, comfort gloves, the helmet with lights and optional TV, and EVA gloves. The two gloves have fingertips of silicone rubber that permit some degree of sensitivity in handling tools and other objects. Metal rings in the gloves snap into rings in the sleeves of the upper torso. The rings in the gloves contain bearings to permit rotation for added mobility in the hand area. The connecting ring of the helmet is similar to the rings used for the body-seal closure. Mobility is not needed in this ring, because the inside of the helmet is large enough for the crewmember's head to move around. To open or lock any of the connecting rings, one or two sliding, rectangular-shaped knobs are moved to the right or the left. When opened, the two halves of the connecting rings come apart easily. To close and lock, one of the rings slides part way into the other against an O-ring seal. The knob is moved to the right, and small pins inside the outer ring protrude into a groove around the inside ring, thereby holding the two together.

All suit openings have locking provisions that require a minimum of three independent motions to open. This feature prevents any accidental opening of suit connections.

With the donning of the helmet and gloves, the spacesuits are now sealed off from the atmosphere of the airlock. The crewmembers are being supported by the oxygen, electricity, and cooling water provided by the orbiter. A manual check of suit seals is made by pressurizing each suit to 29.6 kilopascals d. (The "d" stands for differential, meaning above the airlock pressure.) Inside the airlock, the pressure is either 70.3 or 101 kilopascals. The suit's pressure is elevated an additional 29.6 kilopascals, giving it a pressure differential above the air lock pressure. Once pressure reaches the desired level, the oxygen supply is shut off and the digital display on the chest-mounted control module is read. To assist in reading the display, an optional Fresnel lens inside the space helmet may be used to magnify the numbers. Some leakage of spacesuit pressure is normal. The maximum allowable rate of leakage of the Shuttle EMU is 1.38 kilopascals per minute, and this is checked before the suit is brought back down to airlock pressure.

As the suit pressure is elevated, crewmembers may experience discomfort in their ears and sinus cavities. They compensate for the pressure change by swallowing, yawning, or pressing their noses on an optional sponge mounted to the left on the inside of the helmet ring. Attempting to blow air through the nose when pressing the nose on the sponge forces air inside the ears and sinus cavities to equalize the pressure.

During the next several minutes the two spacesuits are purged of any oxygen/nitrogen atmosphere remaining from the cabin; this is replaced with pure oxygen. Additional suit checks are made while the final oxygen prebreathe takes place.

The inner door of the airlock is sealed, and the airlock pressure bleed-down begins. A small depressurization valve in the airlock latch is opened to outside space, permitting the airlock atmosphere to escape. While this is taking place the EMU automatically drops its own pressure to 66.9 kilopascals and leak checks are conducted. Failure of the leak test would require repressurizing the airlock, permitting the EVA crew to reexamine the seals of their suits.

Final depressurization is begun by opening the airlock depressurization valve. The outer airlock hatch is then opened and the suited astronauts prepare to pull themselves out

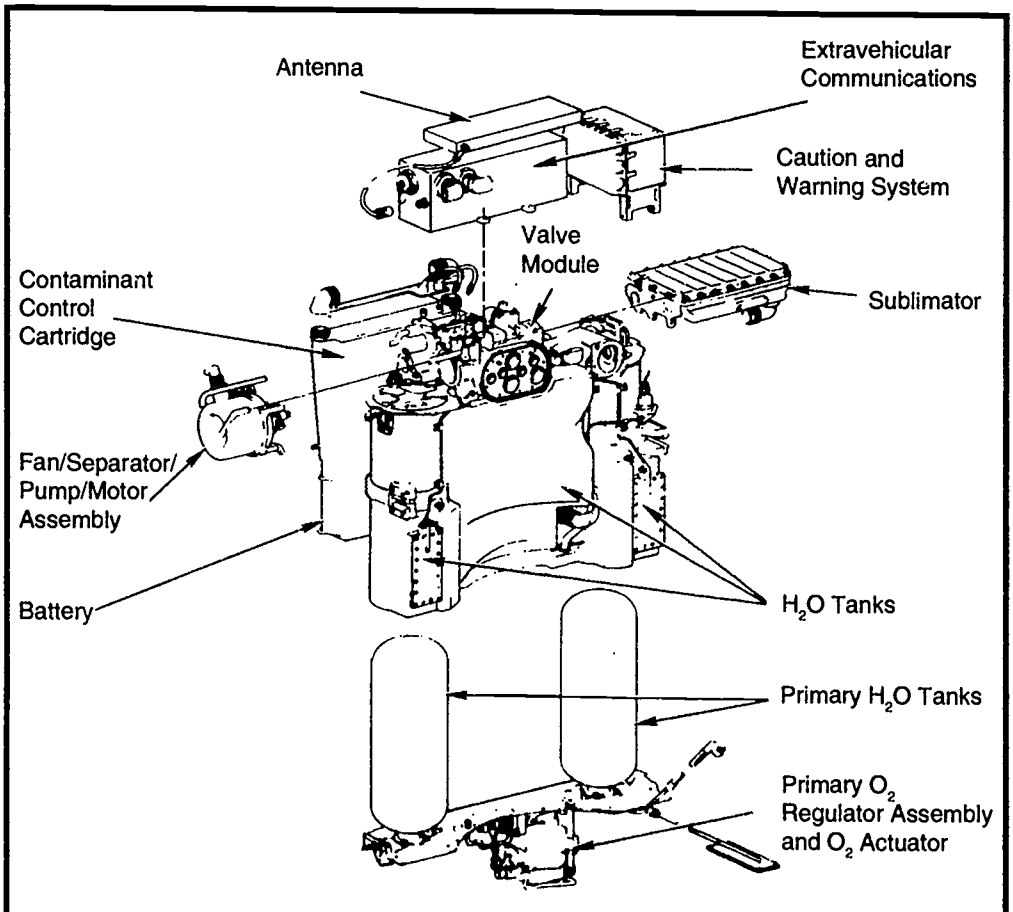
into the payload bay. As a safety measure, they tether themselves to the orbiter to prevent floating away as they move from place to place by hand holds. It is at this point that they disconnect the orbiter Service and Cooling Umbilical from the EMU. The PLSS begins using its own supply of oxygen, cooling water, and electricity. The astronauts pull themselves through the outer airlock hatch, and the EVA begins.

The Primary and Secondary Life-Support Systems

Astronauts experienced their first real freedom while wearing spacesuits during the Apollo Moon-walk EVAs, because of a portable life-support system worn on their backs. All other EVAs up to that time were tied to the spacecraft by the umbilical-tether line that supplied oxygen and kept crewmembers from drifting away. In one sense, the tether was a leash, because it limited movements away from the spacecraft to the length of the tether. On the Moon, however, astronauts were not hampered by a tether and, in the later missions, were permitted to drive their lunar rovers up to 10 kilometers away from the lander. (That distance limit was imposed as a safety measure. It was determined that 10 kilometers was the maximum distance an astronaut could walk back to the lander if a lunar rover ever broke down.)

Space Shuttle astronauts have even greater freedom than the Apollo lunar astronauts, because their EVAs take place in the microgravity environment of space. They do employ tethers when EVAs center in and about the Shuttle's payload bay, but those tethers act only as safety lines and do not provide life support. Furthermore, the tethers can be moved from one location to another on the orbiter, permitting even greater distances to be covered. When activities center some distance from the orbiter, a backpack style of maneuvering system is used, limited in mobility only by the amount of propellants carried in the system.

The freedom of movement afforded to Shuttle astronauts on EVAs is due to the Primary Life-Support System carried on their backs. The PLSS, an advanced version of the Apollo system, provides life support, voice communications, and biomedical telemetry for EVAs lasting as long as seven hours. Within its dimensions of 80 by 58.4 by 17.5 centimeters, the PLSS contains five major groups of compo-



Primary Life-Support System

nents for life support. Those are the oxygen-ventilating, condensate, feedwater, liquid transport, and primary oxygen circuits.

The oxygen-ventilating circuit is a closed-loop system. Oxygen is supplied to the system from the primary oxygen circuit or from a secondary oxygen pack that is added to the bottom of the PLSS for emergency use. The circulating oxygen enters the suit through a manifold built into the Hard Upper Torso. Ducting carries the oxygen to the back of the space helmet, where it is directed over the head and then downward along the inside of the helmet front. Before passing into the helmet, the oxygen warms sufficiently to prevent fogging of the visor. As the oxygen leaves the helmet and travels into the rest of the suit, it picks up carbon dioxide and humidity from the crewmember's respiration. More humidity from perspiration, some heat from physical activity, and trace contaminants are also picked up by the oxygen as it is drawn into the ducting built into the Liquid Cooling-and-Ventilation Garment. A centrifugal fan, running at nearly 20,000 rpm, draws the contaminated oxygen back into the PLSS at a rate of about 0.17 cubic meters per minute, where it passes through the Contaminant Control Cartridge.

Carbon dioxide and trace contaminants are filtered out by the lithium hydroxide and activated charcoal layers of the cartridge. The gas stream then travels through a heat exchanger and sublimator for removal of the humidity. The heat exchanger and sublimator also chill water that runs through the tubing in the Liquid Cooling-and-Ventilation Garment. The humidity in the gas stream condenses out in the heat exchanger and sublimator. The relatively dry gas (now cooled to approximately 13 degrees Celsius) is directed through a carbon dioxide sensor before it is recirculated through the suit. Oxygen is added from a supply and regulation system in the PLSS as needed. In the event of an emergency, a purge valve in the suit can be opened. The purge valve opens the gas-flow loop, permitting the moisture and the carbon dioxide-rich gas to dump outside the suit just before it reaches the Contaminant Control Cartridge.

One of the by-products of the oxygen-ventilating circuit is moisture. The water produced by perspiration and breathing is withdrawn from the oxygen supply by being condensed in the sublimator and is carried by the condensate circuit. (The small amount of oxygen that is also carried by the condensate circuit is removed by a gas separator and returned to the oxygen-ventilating system.) The water is then sent to the water-storage tanks of the feedwater circuit and added to their supply for eventual use in the sublimator. In this manner, the PLSS is able to maintain suit cooling for a longer period than would be possible with just the tank's original water supply.

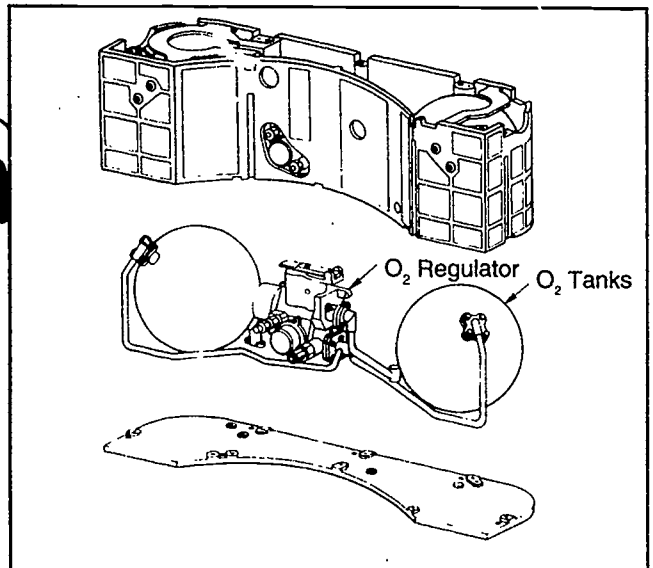
Astronaut Jerry Ross looks into the orbiter windows during the STS-37 mission.

The function of the feedwater and the liquid transport circuits is to cool the astronaut. Using the pressure of oxygen from the primary oxygen circuit, the feedwater circuit moves water from the storage tanks (three tanks holding a total of 4.57 kilograms of water) to the space between the inner surfaces of two steel plates in the heat exchanger and sublimator. The outer side of one of the plates is exposed directly to the vacuum of space. That plate is porous and, as water evaporates through the pores, the temperature of the plate drops below the freezing point of water. Water still remaining on the inside of the porous plate freezes, sealing off the pores. Flow in the feedwater circuit to the heat exchanger and sublimator then stops.

On the opposite side of the other steel plate is a second chamber through which water from the liquid transport circuit passes. The liquid transport circuit is a closed-loop system that is connected to the plastic tubing of the Liquid Cooling-and-Ventilation Garment. Water in this circuit, driven by a pump, absorbs body

heat. As the heated water passes to the heat exchanger and sublimator, heat is transferred through the aluminum wall to the chamber with the porous wall. The ice formed in the pores of that wall is sublimated by the heat directly into gas, permitting it to travel through the pores into space. In this manner, water in the transport circuit is cooled and returned to the LCVG. The cooling rate of the sublimator is determined by the work load of the astronaut. With a greater work load, more heat is released into the water loop, causing ice to be sublimated more rapidly and more heat to be eliminated by the system.

The last group of components in the Primary Life-Support System is the primary oxygen circuit. Its two tanks contain a total of 0.54 kilograms of oxygen at a pressure of 5,860.5 kilopascals, enough for a normal seven-hour EVA. The oxygen of this circuit is used for suit pressurization and breathing. Two regulators in the circuit step the pressure down to



Secondary Oxygen Pack

usable levels of 103.4 kilopascals and 29.6 kilopascals. Oxygen coming from the 103.4-kilopascal regulator pressurizes the water tanks, and oxygen from the 29.6-kilopascal regulator goes to the ventilating circuit.

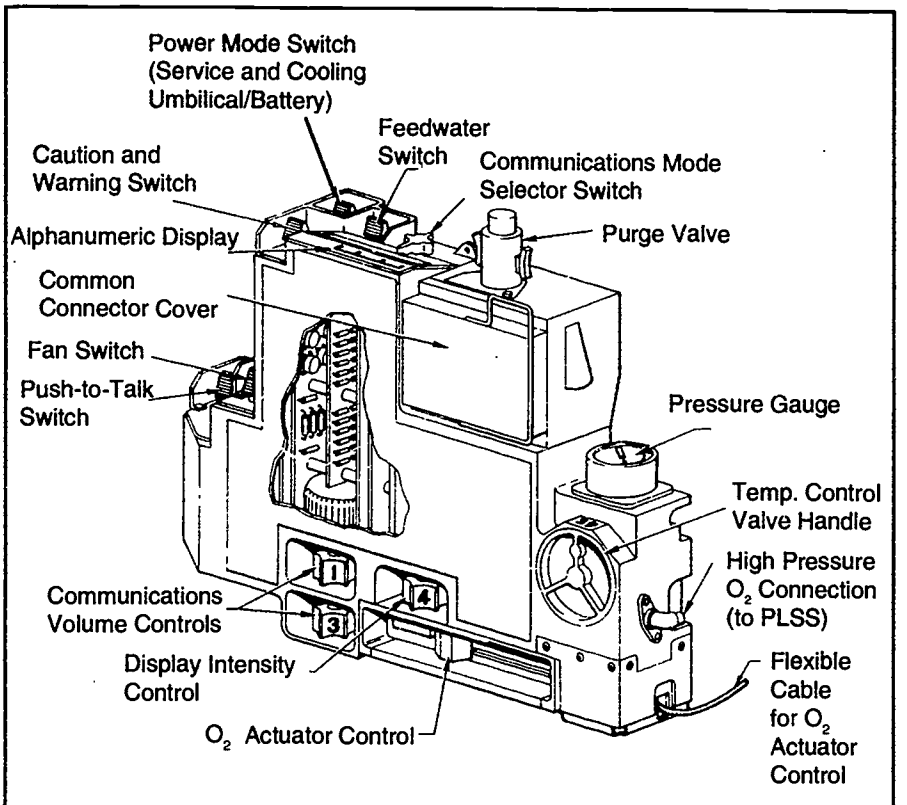
To insure the safety of astronauts on EVAs, a Secondary Oxygen Pack is added to the bottom of the PLSS. The two small tanks in this system contain 1.2 kilograms of oxygen at a pressure of 41,368.5 kilopascals. The Secondary Oxygen Pack can be used in an open-loop mode by activating a purge valve or as a backup supply should the primary system fall to 23.79 kilopascals.

If the Displays and Control Module purge valve (discussed below) is opened, used-oxygen contaminants and collected moisture dump directly out of the suit into space. Because oxygen is not conserved and recycled in this mode, the large quantity of oxygen contained in the SOP is consumed in only 30 minutes. This half-hour still gives the crewmember enough time to return to the orbiter's airlock. If carbon dioxide control is required, the helmet purge valve may be opened. That valve has a lower flow rate than the DCM valve.

Displays and Control Module

The PLSS is mounted directly on the back of the Hard Upper Torso, and the controls to run it are mounted on the front. A small irregularly shaped box, the Displays and Control Module, houses a variety of switches, valves, and displays. Along the DCM top are four switches for power, feedwater, communications mode selection, and caution and warning. A suit-pressure purge valve projects from the top at the left for use with the emergency oxygen system. Near the front on the top is an alpha-numeric display. A microprocessor inside the PLSS permits astronauts to monitor the condition of the various suit circuits by reading the data on the display.

Stepped down from the top of the DCM, on a small platform to the astronaut's right, is a ventilation-fan switch and a push-to-talk switch. (The astronaut has the option of having the radio channel open at all times or only when needed.) On a second platform, to the left, is an illuminated mechanical-suit pressure gauge. At the bottom, on the front of the DCM, are additional controls for communications volume, display lighting intensity, and oxygen flow.



Display and Control Module

Working In Space

One of the great advantages of working in space is that objects, including the astronauts themselves, have no weight. Regardless of the weight of an object on Earth, a single crewmember can move and position that object in orbit with ease provided that the crewmember has a stable platform from which to work. Without that platform, any force exerted to move an object will be met with a corresponding motion of the astronaut in the opposite direction. A simple Earth task, such as turning a nut with a wrench, can become quite difficult, because the astronaut—and not the nut—may turn.

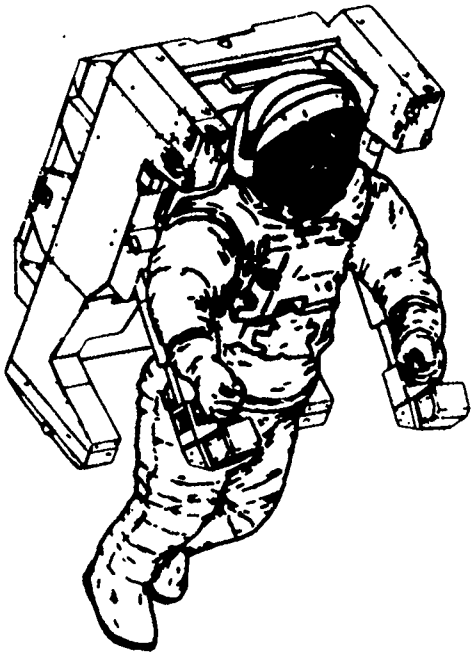
The physics of working in space is the same as that of working on Earth. All people and things contain matter and have mass. Because of that mass, they resist any change in motion. Physicists refer to that resistance as inertia. The greater the mass, the greater the inertia. To change the motion of objects, an application of force is required. According to Sir Isaac Newton's Third Law of Motion, a force causing an object to move one way is met with an equal and opposite force in the other direction. The third law is more familiarly stated as, "For every action there is an equal and opposite reaction." A person planted firmly on the ground can lift heavy objects because the equal and opposite force is directed downward through the legs and feet. The inertia of Earth is so great that the corresponding response to that downward force is infinitesimal.

In space, astronauts do not have the advantage of having a planet to stand on to absorb the equal and opposite force during work activities. Although orbiting objects do not have the property of weight, they still resist change in motion. Pushing on an object causes the object and the crewmember to float away in opposite directions. To gain any advantage over objects, the crewmember must be braced by a stable platform, such as the massive and actively stabilized Shuttle orbiter itself, or must have a self-contained maneuvering system—a kind of "rocket" backpack.

Manned Maneuvering Unit

During the first American EVA, Edward White experimented with a personal propulsion device, the Hand-Held Maneuvering Unit (HHMU). The HHMU tested by White was a three-jet maneuvering gun. Two jets were located at the ends of rods and aimed back, so that firing them pulled White forward. A third jet was aimed forward to provide a braking force. By holding the gun near his center of mass and aiming it in the direction in which he wanted to travel, he was able to propel himself forward.

Stopping that movement required firing the center jet. The propulsive force of the HHMU was produced by releasing compressed oxygen from two small built-in tanks.



Although the HHMU worked as intended, it had two disadvantages. To produce the desired motion, it had to be held as close to the astronaut's center of mass as possible. Determining the center position was difficult because of the bulky spacesuit White wore, and was a matter of guesswork and experience. Furthermore, precise motions to position an astronaut properly during an activity such as servicing a satellite were difficult to achieve and maintain, and proved physically exhausting.

On the Gemini 9 mission, a backpack maneuvering unit was carried. However, problems with the unit prevented Gene Cernan from testing it.

Following the Gemini program, the next space experiments that tested maneuvering units for EVAs took place during the second and third manned Skylab missions. The device was tested only inside the spacecraft, but the experiment confirmed that a maneuvering device of that design was both feasible and desirable for future EVA use. The experiments were dubbed M-509. Five of the six astronauts who flew in those two missions accumulated a total of 14 hours testing the advanced device, called the AMU, or Astronaut Maneuvering Unit. The AMU was shaped like a large version of a hiker's backpack. Built into the frame was a replaceable tank of compressed nitrogen gas. Controls for the unit were placed at the ends of "arm rests." To move, the astronaut worked rotational and translational, or nonrotational, hand controls. Propulsive jets of nitrogen gas were released from various nozzles spaced around the unit. The 14 nozzles were arranged to aim top-bottom, front-back, and right-left to produce six degrees of freedom in movement. The AMU could move forward and back, up and down, and side to side, and could roll, pitch, and yaw. With the 11 additional nozzles, precise positioning with the AMU was far simpler than with the HHMU of the Gemini program. The astronaut was surrounded by the unit, taking the guesswork out of determining center of mass and making control much more accurate. The astronaut could move closely along the surface of a curved or irregularly shaped object without making contact with it.

The Manned Maneuvering Unit of the Space Shuttle is an advanced version of the Skylab AMU. It is designed to operate in the microgravity environment of outer space and under the temperature extremes found there. The MMU is operated by a single space-suited astronaut. The unit features redundancy to protect against failure of individual systems. It is designed to fit over the life-support system backpack of the Shuttle EMU.

The MMU is approximately 127 centimeters high, 83 centimeters wide, and 69 centimeters deep. When carried into space by the Shuttle, it is stowed in a support station attached to the wall of the payload bay near the airlock hatch. Two MMUs are normally carried on a mission, and the second unit is mounted across from the first on the opposite payload bay wall. The MMU controller arms are folded for storage, but when an astronaut backs into the unit and snaps the life-support system into place, the arms are unfolded. Fully extended, the arms increase the depth of the MMU to 122 centimeters. To adapt to astronauts with different arm lengths, controller arms can be adjusted over a range of approximately 13 centimeters. The

MMU is small enough to be maneuvered with ease around and within complex structures. With a full propellant load, its mass is 148 kilograms.

Gaseous nitrogen is used as the propellant for the MMU. Two aluminum tanks with Kevlar filament overwrappings contain 5.9 kilograms of nitrogen each at a pressure of 20.68 kilopascals, enough propellant for a six-hour EVA, depending on the amount of maneuvering done. In normal operation, each tank feeds one system of thrusters. In the event some of the thrusters fail, crossfeed valves may be used to connect the two systems, permitting all propellant from both tanks to be used. At the direction of the astronaut, through manual control or at the direction of an automatic attitude-hold system, propellant gas is moved through feed lines to varying combinations of 24 nozzles arranged in clusters of three each on the eight corners of the MMU. The nozzles are aimed along three axes perpendicular to each other and permit six degrees of freedom of movement. To operate the propulsion system, the astronaut uses his or her fingertips to manipulate hand controllers at the ends of the MMU's two arms. The right-hand controller produces rotational acceleration for roll, pitch, and yaw. The left controller produces acceleration without rotation for moving forward-back, up-down, and left-right. Orders pass from the hand controls through a small logic unit (Control Electronics Assembly) that operates the appropriate thrusters for achieving the desired acceleration. Coordination of the two controllers produces intricate movements in the unit. Once a desired orientation has been achieved, the astronaut can engage an automatic attitude-hold function that maintains the inertial attitude of the unit in flight. This frees both hands for work. Any induced rotations produced by the astronaut's manipulating payloads and equipment or by changes in the center of gravity are automatically countered when sensed by small gyros.

Using the MMU

When it becomes necessary to use the MMU, an astronaut first enters the orbiter's airlock and dons a spacesuit. Exiting into space, the astronaut attaches a safety tether and moves along handholds to the MMU. The maneuvering unit is attached to the payload-bay wall with a framework that has stirrup-like foot restraints. Facing the MMU and with both feet in the restraints, the crewmember visually inspects

Bruce McCandless II pilots the MMU in space for its first flight.

the unit. If battery replacement is necessary or if the propellant tanks need recharging, those tasks can be accomplished at this time. When ready, the astronaut turns around and backs into position. The life-support system of the suit locks into place, hand-controller arms are unfolded and extended, and the MMU is released from the frame.

While maneuvering, the astronaut must use visual cues to move from one location to another. No other guidance system is necessary. The only contact with the orbiter during maneuvering is through the EMU radio voice-communication equipment.

While flying the MMU, the crewmember keeps track of the propellant supply with two gauges located on either side of his or her head. Keeping track of the supply is important

because when it is depleted no additional maneuvering is possible. This means that the astronaut must keep in reserve for the return to the orbiter at least as much propellant as was expended in flying out to the satellite. The rest of the load can be used for maneuvering on station with the target. Generally, a total velocity change of 20.1 meters per second is possible on one flight. Furthermore, that delta velocity, as it is called, must be divided in half so that propellant will be available for the trip back. It is divided in half again to allow for rotational accelerations. Generally, astronauts fly the MMU at velocities of only 0.3 to 0.6 meters per second relative to the Shuttle. While these velocities may seem small, they accomplish much in the microgravity environment of Earth orbit. Once an astronaut begins moving in a new direction or at a new velocity, he or she will keep moving indefinitely until an opposing thrust is applied.

Upon completion of assigned tasks, the astronaut returns to the payload bay and reverses the unstowing procedure. To assist in realignment with the mounting frame, large mushroom-like knobs, built into the frame, are available for grasping by the crewmember as he or she pushes backwards onto the frame.

Future Space Suits

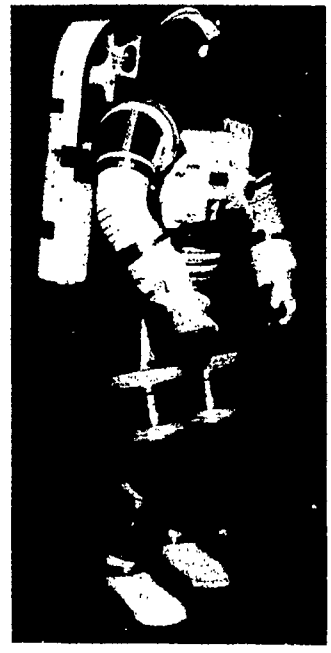
The Space Shuttle Extravehicular Mobility Unit, Manned Maneuvering Unit, and all the associated EVA systems are the result of many years of research and development. They now comprise a powerful tool for orbital operations, but they are not end-of-the-line equipment. Many improvements are possible: the spacesuit of the future may look dramatically different from the Space Shuttle EMU.

Advanced versions of the EMU are being studied, including spacesuits that operate at higher pressures than the current EMU. The advantage of higher operating pressures is that virtually no time will be lost to prebreathing in preparation for EVA.

To build an operational high-pressure suit requires improved joint technology and integration of those joints into the suit. Under consideration are fabric and metal suits and suits with a hard external shell. Most of the technology needed for these suits has already been tested. One of the biggest challenges is to make a highly mobile glove. At higher operating pressures, fingers of older-style spacesuit gloves become so increasingly stiff that finger dexterity is severely reduced. Research to address this problem has led to the development of high-pressure gloves made with metal bands for knuckle and palm joints. These gloves show potential for use with future suits as well as with current suits.

A prototype of a next-generation spacesuit is tested.

Another potential advantage of high-pressure suits is that they can be designed to be serviced and resized in orbit. Current EMUs can be used in space for up to 21 hours before they have to be completely cleaned and checked out on Earth. One new EMU potentially could be used for several hundred hours in space before a return to Earth is necessary. This capability will be vital when the United States constructs its first permanent space station in orbit. There,



A spacesuit technician tests a high-pressure hard suit.

crewmembers will remain in space for months at a time, and EVAs for station maintenance could become a routine event.

Another suit improvement is a "heads-up display" for reading the instruments on the EMU chest-mounted displays and control module. Heads-up displays are currently being used in the cockpits of commercial and military aircraft as well as on the flight deck of the Shuttle orbiter. These displays reflect instrument readings on a transparent screen so that a pilot can look straight out the window while landing instead of continually tilting his or her head down to check readings. A heads-up display should make DCM readings easier to see in sunlight and eliminate the need for Fresnel lenses or bifocals for some crewmembers.

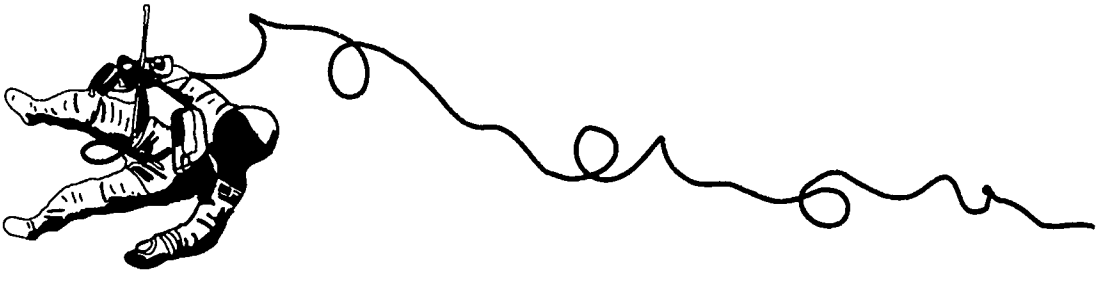
The Manned Maneuvering Unit is also undergoing redesign. Although the exterior of the MMU is likely to remain the same, important changes are due on the inside. Larger nitrogen tanks, with greater operating pressures, could lead to substantially increased operational range in space.

Still further into the future, spacesuits will change to meet the demands of new missions. For the most part, the design of a spacesuit is based on the environment in which it is designed to operate. Space Shuttle spacesuits for use in Earth orbit are designed to operate in a vacuum and microgravity. A spacesuit for use on the surface of Mars, however, will require a different design. A Space Shuttle style of spacesuit would weigh about 43 kilograms on Mars. Consequently, lighter EMU structures will be needed to lessen the load a future Martian explorer will carry. In addition, the thin Martian atmosphere provides too much pressure for a cooling sublimator to work. Some other cooling strategy will have to be devised. Still another concern is to provide protection from dust that is carried by Martian winds and will be kicked up by the explorers. These and other properties of the Martian environment provide interesting and exciting challenges to spacesuit designers and builders.

EVA

Starting with Edward White's spacewalk in 1965, American astronauts have logged many hundreds of hours of extravehicular activity in space. Mission planners correctly foresaw the role EVA would play in future space missions. The early Gemini experience was primarily experimental. During the Apollo and Skylab programs, EVA was critical to success. With the Space Shuttle, it is even more critical. The Shuttle, in spite of its complexity, is really a kind of space truck. It is a means—an economical transportation system—for getting payloads into space and returning them to Earth. Enhancing the Shuttle's capability is the Extravehicular Mobility Unit. By donning the EMU and attaching a Manned Maneuvering Unit, an astronaut becomes a small, short-term spacecraft. Space-suited crewmembers can manipulate payloads, make adjustments, repair broken parts, join pieces together, and handle a host of other activities. Most important, they bring with them the human ability to cope with unexpected or unusual situations that occur in the hard and unforgiving vacuum of outer space.

With the capability of astronauts to go EVA, the Space Shuttle is more than just a transportation system. It is a satellite servicing vehicle, a space structure assembly base, an assembly tool for future space station construction, and a way station for preparing for deep space research missions. EVA is a vital part of America's future in space.



Classroom Activities

The activities and related student projects that follow emphasize hands-on involvement of the students. Where possible, they make use of inexpensive and easy-to-find materials and tools. The activities are arranged into four basic units, each relating to a different aspect of spacesuits and spacewalking.

Unit 1: Investigating the Space Environment

Objectives: To demonstrate how very different the space environment is from the environment at the surface of Earth.

To illustrate why spacesuits must be worn by astronauts going on a spacewalk.

Unit 2: Dressing for Spacewalking

Objectives: To demonstrate how spacesuits create a livable environment for astronauts.

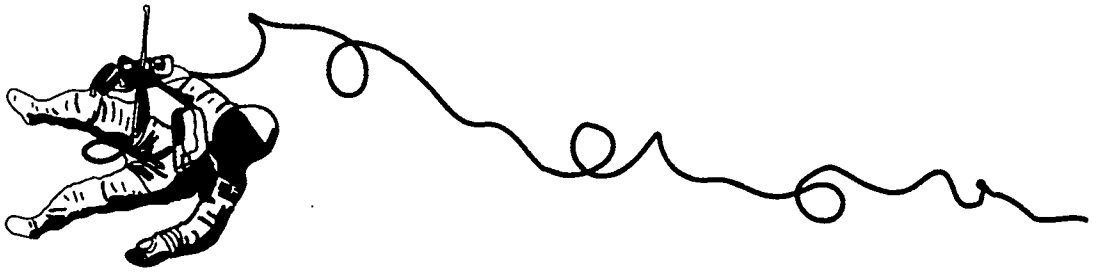
To illustrate some of the complexities involved in constructing a usable spacesuit.

Unit 3: Moving and Working in Space

Objective: To experience the problems astronauts face when trying to move and work in space and understand how those problems are solved.

Unit 4: Exploring the Surface of Mars

Objective: To design, through a team effort, a spacesuit for future use on the planet Mars.



Unit 1

Investigating the Space Environment

Activity 1: A Coffee Cup Demonstrates Microgravity

Topic: Microgravity in space

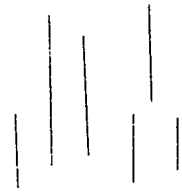
Description: A stream of water coming out of a hole in a cup stops when the cup is dropped.

Materials Needed:
Styrofoam or paper coffee cup
Pencil or other pointed object
Water
Bucket or other catch basin

Procedure:

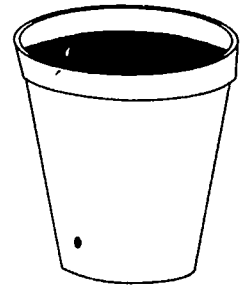
Step 1. Punch a small hole in the side of the cup near its bottom.

Step 2. Hold your thumb over the hole as you fill the cup with water. Ask students what will happen if you remove your thumb.



Step 3. Remove your thumb and let the water stream out into the catch basin on the floor.

Step 4. Again seal the hole with your thumb and refill the cup. Ask students if the water will stream out of the hole if you drop the cup.



Step 5. Drop the filled cup into the catch basin. The demonstration is more effective if you hold the cup high before dropping it.

Discussion:

Earth-orbiting spacecraft experience a condition described as microgravity. The spacecraft is in a state of free-fall as it orbits. If the spacecraft has astronauts on board, the astronauts are able to move about with ease because they too are in a state of free-fall. In other words, everything in their immediate world is falling together. This creates the microgravity condition. Crewmembers and all the other contents of the spacecraft seemingly float through the air.

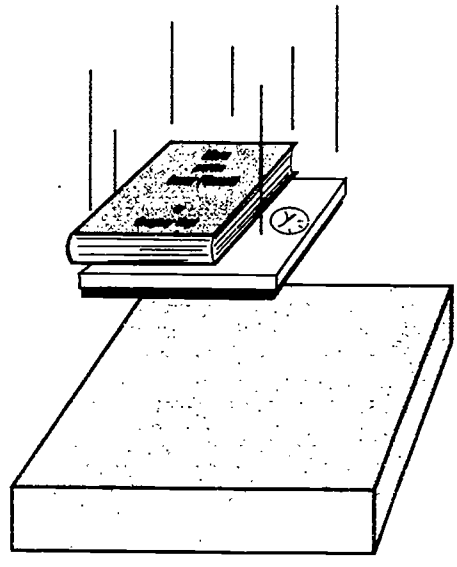
On Earth, momentary microgravity can be created in a number of ways. Some amusement parks achieve a second or two of microgravity in certain wild high-tech rides. A springboard diver feels a moment of microgravity at the top of a spring just as the upward motion stops and just before the downward tumbling motion to the water below begins. As the diver falls, friction with air quickly offsets the microgravity sensation and produces drag that returns at least a portion of the diver's weight before the water is struck. NASA eliminates the air friction problem and achieves about 30 seconds of microgravity with a special airplane. High above Earth, the plane begins a long arc-like dive downward at a speed equal to the acceleration of a falling object. After 30 seconds, the plane pulls out of the dive and climbs back to the high altitude to begin another microgravity cycle. The airplane's skin and engine thrust during the dive totally negate air friction on the people and experiments in the plane.

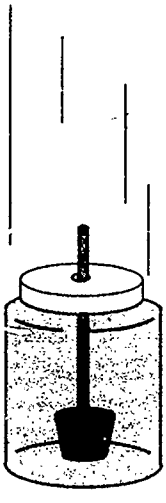
The falling cup for a moment demonstrates microgravity (or sometimes incorrectly referred to as weightlessness or zero-g). When the cup is stationary, water freely pours out of the cup. If the cup falls, the water remains inside the cup for the entire fall. Even though the water remains inside, it is still attracted to Earth by gravity and ends up in the same place that the water from the first experiment did.

The demonstration works best when students are asked to predict what will happen when the cup is dropped. Will the water continue to pour out the hole as the cup falls? If your school has videotape equipment, you may wish to videotape the demonstration and then use the slow motion controls on the playback machine to replay the action.

Additional Demonstrations on Microgravity:

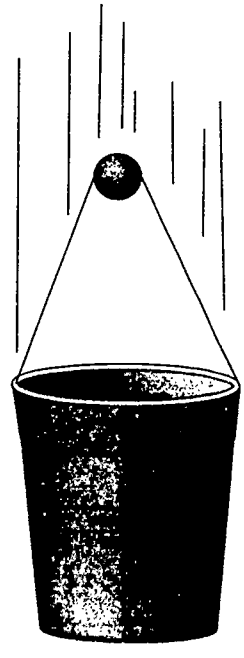
- Place a heavy book on a bathroom scale. Note the book's weight. Drop the book and scale together from a height of about a meter on to a mattress or some pillows. As it drops, quickly observe the book's weight. (The book's weight becomes zero as it falls.)





- Cut a small hole in the lid of a clear plastic jar. Drill a hole into a cork stopper and insert one end of a drinking straw into the stopper. Fill the jar with water and place the cork inside the jar with the straw extending through the hole. Push the cork to the bottom. Hold the jar a couple of meters off the floor and drop it into someone's hands. As it falls, watch the cork and straw. (During free-fall, the buoyancy of the cork disappears.)

- You can show how objects appear to float in microgravity by tieing a wooden bead to a paper cup with thread and dropping them together. Assemble the demonstration as shown in the illustration. Because of air friction, it may be necessary to add a few paper clips to the bottom of the cup to make it fall as fast as the bead. Hold the cup high in the air by the bead and drop it to the floor. Observe the bead and cup as they fall. Try letting go of the bead again, but this time hold on to the bottom of the cup. How does this demonstration show that freefall creates microgravity?



Activity 2: Meteoroids and Space Debris

Topic: Potential hazard to spacewalkers from meteoroids and space debris

Description: The penetrating power of a projectile with a small mass but high velocity is demonstrated.

Materials Needed:
Raw baking potato
Large-diameter plastic straw

Procedure:

Step 1. Hold a raw potato in one hand. While grasping the straw with the other hand, stab the potato with a quick, sharp motion. The straw should penetrate completely through the potato. **Caution: Be careful not to strike your hand.**

Step 2. Again hold the potato and this time stab it with the straw using a slow push. The straw should bend before penetrating the potato very deeply.

Discussion:

Astronauts on spacewalks are likely to encounter fast-moving rocky particles called meteoroids. A meteoroid can be very large with a mass of several thousand metric tons, or it can be very small—a micrometeoroid about the size of a grain of sand. Every day Earth's atmosphere is struck by hundreds of thousands or even millions of meteoroids, but most never reach the surface because they are vaporized by the intense heat generated when they rub against the atmosphere. It is rare for a meteoroid to be large enough to survive the descent through the atmosphere and reach solid Earth. If it does, it is called a meteorite.

In space there is no blanket of atmosphere to protect spacecraft from the full force of meteoroids. It was once believed that meteoroids traveling at velocities averaging 80 kilometers per second would prove a great hazard to spacecraft. However, scientific satellites with meteoroid detection devices proved that the hazard was minimal. It was learned that the majority of meteoroids are too small to penetrate the hull of spacecraft. Their impacts primarily cause pitting and sandblasting of the covering surface.

Of greater concern to spacecraft engineers is a relatively recent problem—spacecraft debris. Thousands of space launches have deposited many fragments of launch vehicles, paint chips, and other "space trash" in orbit. Most particles are small, but traveling at speeds of nearly 30,000 kilometers per hour, they could be a significant hazard to spacecraft and to astronauts outside spacecraft on extravehicular activities.

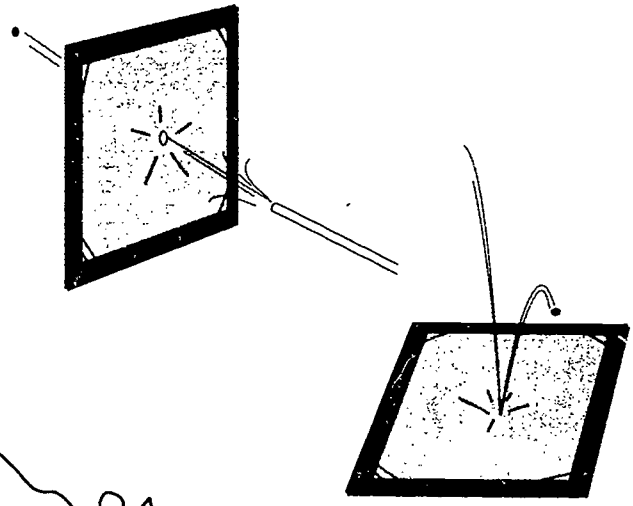
Engineers have protected spacecraft from micrometeoroids and space trash in a number of ways, including construction of double-walled shields. The outer wall, constructed of foil

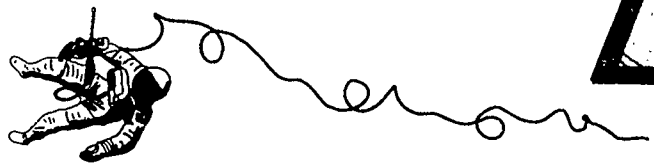
and hydrocarbon materials, disintegrates the striking object into harmless gas that disperses on the second wall. Spacesuits provide impact protection through various fabric-layer combinations and strategically placed rigid materials.

Although effective for particles of small mass, these protective strategies do little if the particle is large. It is especially important for spacewalking astronauts to be careful when they repair satellites or do assembly jobs in orbit. A lost bolt or nut could damage a future space mission through an accidental collision.

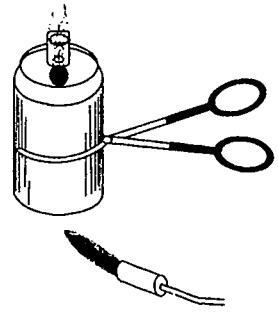
Additional Demonstration on Meteoroids and Space Debris:

- Aim a pea shooter at a piece of tissue paper taped to a cardboard frame. Aim the shooter at the tissue paper and blow hard into the shooter to accelerate the pea to the tissue at a high velocity. Drop the pea on to the tissue paper from a height of two meters. In the first demonstration the pea will penetrate the tissue, but in the second the pea will bounce.





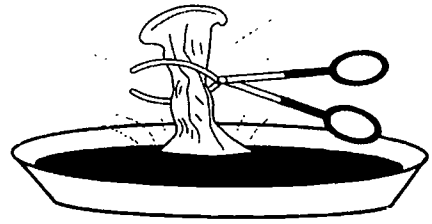
Activity 3: Air Pressure Can Crusher



Topic: Vacuums

Description: Air pressure exerts a force that crushes an aluminum beverage can.

Materials Needed:
Aluminum beverage can
Tongs to hold the can
Dish of cold water
Heat source (propane torch set at low flame, alcohol lamp)
Eye protection for demonstrator
Towel for cleanup



Procedure:

Step 1. Place approximately 30 ml of water in the can and heat it to boiling. Permit the water to boil for at least 30 seconds before removing it from the heat.

Step 2. Immediately invert the can and thrust its top (end with the opening) a short distance into the cold water. The can will collapse implosively. **Caution: Avoid splashing the boiling water.**

Discussion:

The crushed can in this activity demonstrates the force of air pressure. An absence of pressure is a deadly hazard of space flight.

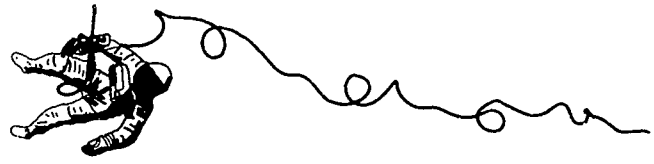
The can collapses because a partial vacuum has been created inside and its metal walls are not strong enough to sustain its original shape against the outside air pressure. The first step in creating the vacuum is to boil the water inside the can to produce steam. After approximately 30 seconds of boiling, the air in the can is replaced by the steam. When the can is inverted into the cold water, a rapid temperature drop takes place, causing the steam to return to water drops. What is left is a vacuum. Since the opening of the can is sealed with water in the dish, the can collapses before water in the dish has a chance to fill the void.

The amount of air pressure on the can may be calculated by determining the surface area of the can and multiplying this by a sea-level air pressure of 101 kilopascals:

Surface area of can = area of cylinder + area of 2 ends

or

Surface area of can = $2 \pi r \times \text{length} + 2 \times \pi r^2$

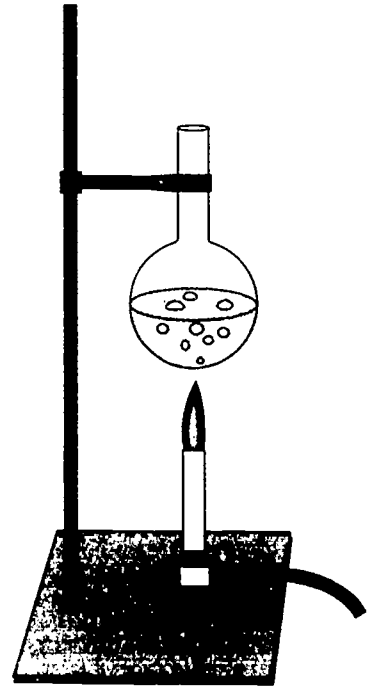


Activity 4: Boiling Water With Ice

Topic: Vacuums

Description: A sealed flask of hot water is brought to a boil by immersing it in ice water.

Materials Needed:
Pyrex glass boiling flask (round or flat bottom)
Solid rubber stopper to fit flask
Bunsen burner or propane torch (flame spreader optional)
Ring stand and clamp
Aquarium filled with ice water
Eye protection for anyone standing near the boiling flask



Procedure:

Step 1. Fill the flask to about one-third capacity with water and attach to the ring stand.

Step 2. Heat the bottom of the flask until the water begins to boil.

Step 3. Remove the heat source. When the boiling stops, insert the stopper.

Step 4. Free the clamp from the stand and immerse the entire flask in the aquarium. Be sure the side of the aquarium is wiped free of condensation so that the flask can easily be seen. Observe what happens to the water in the flask.

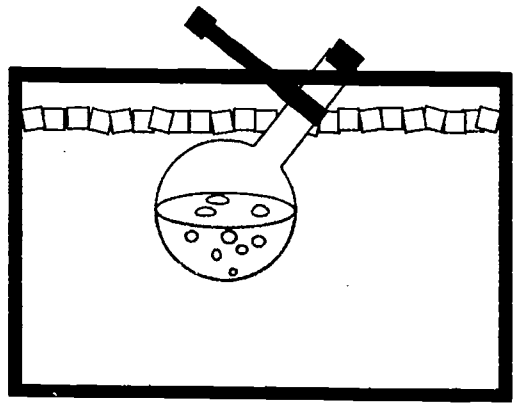
Discussion:

Water boils when its temperature reaches 100 degrees C. The act of boiling changes the state of matter from liquid into gas. In doing so, heat is carried away by the gas, so that the remaining liquid cools below the boiling point. Consequently, continuous heating is necessary until all the liquid is converted to gas.

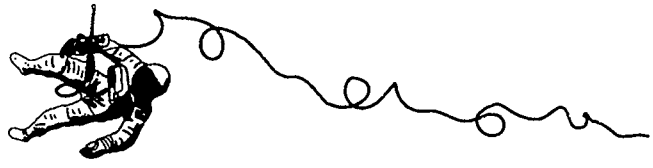
Although the boiling temperature of water appears to be fixed, it is not. It varies with air pressure. Water boils at 100 degrees C at a sea-level pressure of 101 kilopascals. However, water's boiling temperature drops as air pressure drops, and air pressure drops with elevation above sea level. (Because of depressed boiling temperatures at higher elevations, many commercial cake mixes come with instructions for increasing baking times if the cake is going to be baked in a mountain home.)

At very low atmospheric pressures, such as those encountered at elevations higher than 18 km above sea level, water boils spontaneously even at room temperature. This creates a problem for pilots of high-altitude research planes and astronauts in space. The human body is approximately 60% water. At very low atmospheric pressures, body water contained within the skin would begin to boil, and the skin would start inflating. Needless to say, this is a very unpleasant experience and one that can be fatal if it persists for too many seconds. High-altitude pilots and astronauts on extravehicular activity require pressure-suit protection for survival.

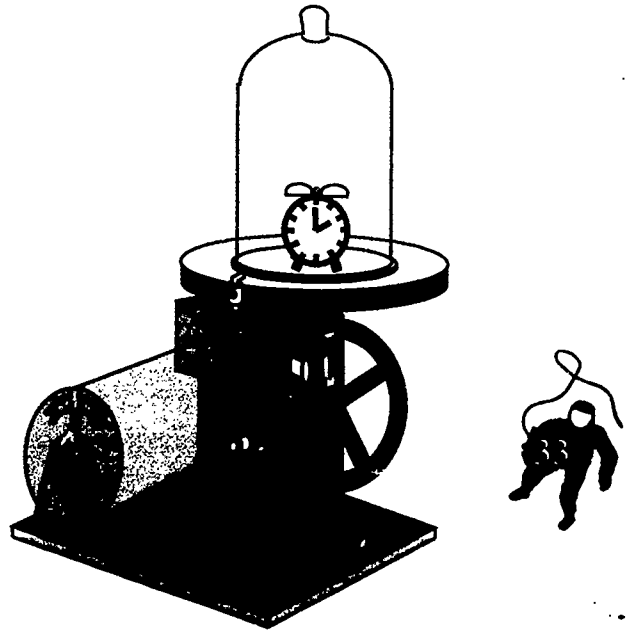
This demonstration shows the effect of lowered pressure on the boiling point of water. When the water has stopped boiling and the flask is sealed, it is thrust into chilled water. The temperature of the hot, moist air above the water in the flask is quickly lowered and it contracts, thereby lowering the pressure inside the flask. With the lowered pressure, the water, even though its temperature has actually lowered, begins boiling again. Boiling will stop shortly as the pressure in the flask increases due to newly released gas.



Note: The rubber stopper may be difficult to remove from the flask once the water inside the flask has cooled. Simply reapply heat to the flask and remove the stopper as air pressure inside increases. **Be sure to wear eye protection while doing this.**



Additional Demonstrations on Vacuums:



Additional demonstrations on the properties of the vacuum found in space can be done with a vacuum pump, vacuum plate, and bell jar. This apparatus is available through science supply catalogs, and many schools have them in their equipment inventories. If your school does not have this equipment, it may be possible to borrow it from another school.

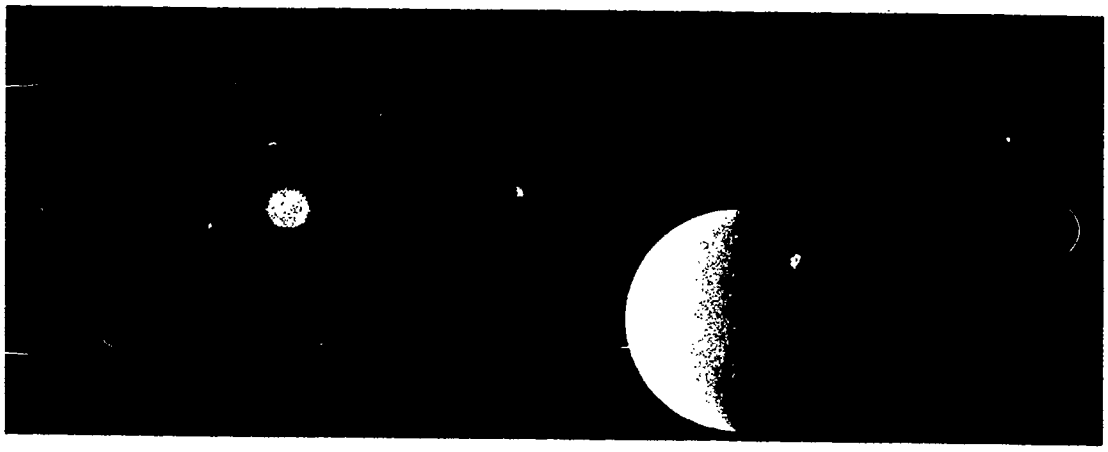
- Set the alarm on a windup alarm clock to ring in a few minutes. Place the clock on the vacuum plate, cover with the bell jar, and evacuate the air. When the alarm goes off, it will be possible to see but not hear the clock ring. There is no air inside the chamber to conduct the sound waves from the ringing of the bell. Some sound may conduct through the vacuum plate, however, through its contact with the clock feet. This demonstration illustrates why radios are built into spacesuits. Contrast this demonstration with science fiction movies in which sounds from explosions are heard through space.

- Obtain a clear balloon or a clear plastic freezer bag. Put water in the balloon or bag and seal. Place the balloon or bag on the vacuum plate, cover with the bell jar, and evacuate the chamber. Observe the boiling that takes place in the water and how the balloon or bag begins to inflate. The inflation provides an analogy to the way exposed skin will inflate in a vacuum because of the gas bubbles that form in the liquid contained in cells.

Student Project 1: Earth Is a Spaceship

Topic: Earth as a life-support system for travel through space

Background Information: Every 365 days, 5 hours, and 46 minutes, Earth completes an orbit around the Sun. To do so, it travels at a speed of 109,500 km per hour. At the same time this is happening, our Sun and all its planets are traveling in the direction of the star Vega at a speed of 20 km per second. As a part of the Milky Way galaxy, we are also orbiting the galactic center at a speed of about 250 km per second. Finally, the Milky Way is on its own voyage through the universe at a speed of 600 km per second. Combining all these motions together, we discover that Earth is actually a spaceship, hurtling us through space at the incredible speed of approximately 900 km per second, or nearly 30 billion km per year!



Writing Assignment: Like astronauts traveling on rockets or moving about through outer space in their spacesuits, earthling astronauts need protection from the hazards of space.

- Write an essay about spaceship Earth. What "services" does Earth provide for human life-support? How do the ways Earth provides these services compare with the way the life-support system of a spacesuit functions? Why is it important to protect our life-support systems?
- Write a short story on what might happen to our spaceship if we do not take care of it.

Art Project: Create a mural, collage, or mobile that illustrates the spaceship Earth concept.

Mathematics Assignment: Compare the travel of spaceship Earth with terrestrial locomotion–such as walking, running, automobiles, trains, airplanes–and with the Space Shuttle. How long would it take a person in an automobile (train, plane, etc.) to travel the distance Earth travels through space in just one hour?

Historical Research: Try to learn who first proposed the concept of Earth as a spaceship and the event that led to the development of this environmental concept.

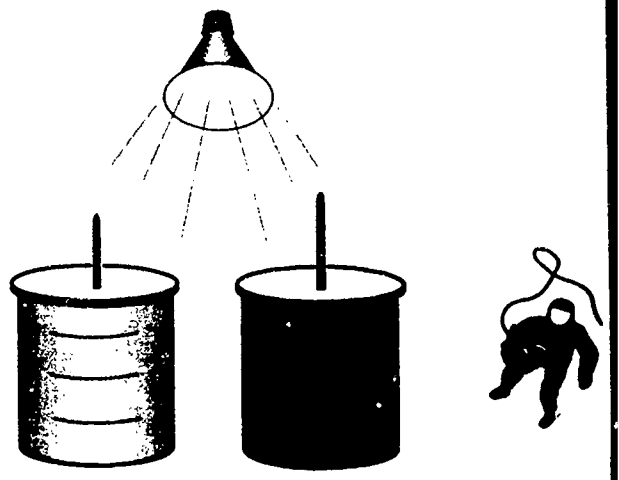
Unit 2

Dressing for Spacewalking

Activity 1: Choosing the Right Color

Topic: Spacesuit design

Description: The relative effects of light versus dark surfaces on heat absorption and radiation are investigated.



Materials Needed:
2 Coffee cans with plastic snap lids
2 Thermometers (dial or glass)
Spray paint (white and black)
Flood lamp and light fixture
Stopwatch or watch with a second hand
Graph paper

Procedure:

Step 1. Spray-paint the outside of one coffee can black and spray the other white.

Step 2. Snap on the plastic lids and punch a hole in the center of each lid. Insert one thermometer into each lid.

Step 3 Direct the light from a flood lamp at the sides of the two cans. Make sure it is equidistant from both cans.

Step 4. Begin recording temperatures starting with an initial reading of each thermometer, and take readings thereafter every 30 seconds for the next 10 minutes. Extend the time beyond 10 minutes if you wish.

Step 5. Plot the temperature data on graph paper, using a solid line for the black can and a dashed line for the white can. Construct the graph so that the data for temperature are along the Y (vertical) axis and for time along the X (horizontal) axis.

Step 6. Compare the slope of the temperature plots for the white and black cans.

Discussion:

It is not by chance or for aesthetics that the outer layer of a spacesuit is constructed of a durable white fabric. Environments in outer space fluctuate from shade to full sunlight. In full Sun, the temperature will rise to 120 degrees C and in shade drop to minus 100 degrees C. Such extremes are constantly being encountered by astronauts out on extravehicular activities. The side of the astronaut facing the Sun cooks while the side in shade freezes.

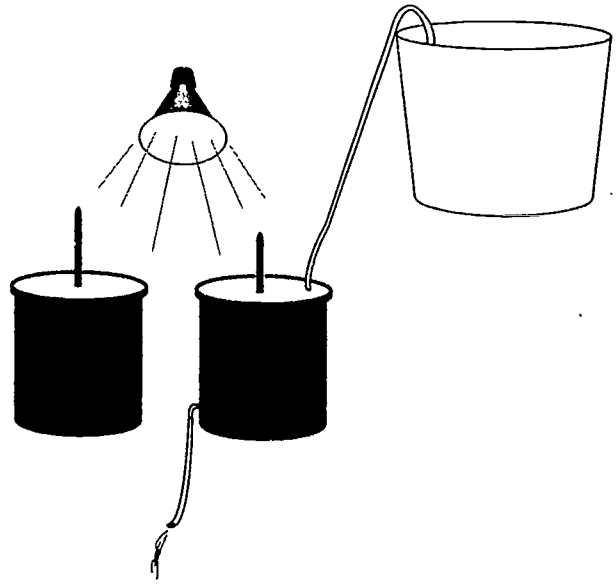
One of the challenges in spacesuit design is to maintain a comfortable working temperature inside. A liquid cooling-unit inside the suit helps moderate body heat caused by the astronaut's physical exertion, but the heat coming into the suit from the outside and the heat escaping from the suit to the outside must be moderated as well. Several inside layers provide insulation, but that is not enough to protect the crew member. White fabric on the outside of the suit is used because it absorbs less heat than does dark fabric.

Activity 2: Keeping Cool

Topic: Spacesuit design

Description: The functioning of the liquid cooling-garment of spacesuits is demonstrated.

Materials Needed:
2 Coffee cans with plastic snap-on lids
2 Thermometers (dial or glass. Must be able to read a full range of temperatures from freezing to boiling.)
Spray paint (black)
Floodlight and light fixture
Plastic aquarium tubing (6 meters)
Masking tape
2 Buckets
Ice
Water
Stopwatch or watch with a second hand
Graph paper
Metal punch or drill



Procedure:

Step 1. Spray-paint the outside of both cans black and permit them to dry.

Step 2. Punch a hole in the center of each lid and insert a thermometer. Punch a second hole in one of the lids large enough to admit the aquarium tubing. Also punch a hole in the side of one of the two cans near its base.

Step 3. Form a spiral coil with the plastic tubing along the inside wall of the can with the hole punched in its side. Do not pinch the tube. Extend the tube's ends out of the can, one through the hole in the can and the other through the hole in the lid. The upper end of the tube should reach into the elevated water bucket and the other should hang down from the side of the can toward the lower bucket.

Step 4. Set up the floodlight so that it shines on the sides of the two cans. Make sure the light is equidistant from the two cans.

Step 5. Fill one bucket with ice and water. Make sure there is enough ice to chill the water thoroughly.

Step 6. Elevate the ice water bucket on a box or some books next to the can with the tubing.

Step 7. Insert the long end of the aquarium tubing into the ice water bucket to the bottom. Using your mouth, suck air from the other end of the tube to start a siphoning action. Permit the water to drain into a second bucket on the floor.

Step 8. Immediately turn on the floodlight so that both cans are equally heated.

Step 9. Begin recording temperatures, starting with an initial reading of each thermometer just before the light is turned on and every 30 seconds thereafter until the water runs out.

Step 10. Plot the temperature data on graph paper, using a solid line for the can that held the ice water and a dashed line for the other can. Construct the graph so that the temperature data are along the Y (vertical) axis and those for time along the X (horizontal) axis.

Step 11. Compare the slope of the plots for the two cans.

Discussion:

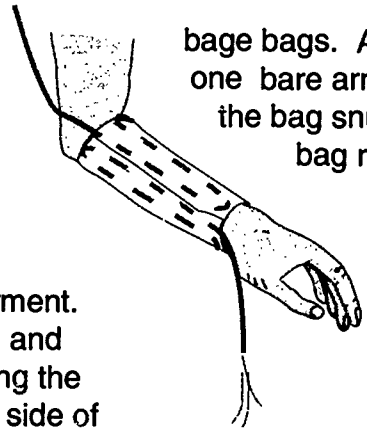
Astronauts out on extravehicular activity are in a constant state of exertion. Body heat released from this exertion can quickly build up inside a spacesuit, leading to heat exhaustion. Body heat is controlled by a liquid cooling-garment made from stretchable spandex fabric and laced with small-diameter plastic tubes that carry chilled water. The water is circulated around the body. Excess body heat is absorbed into the water and carried away

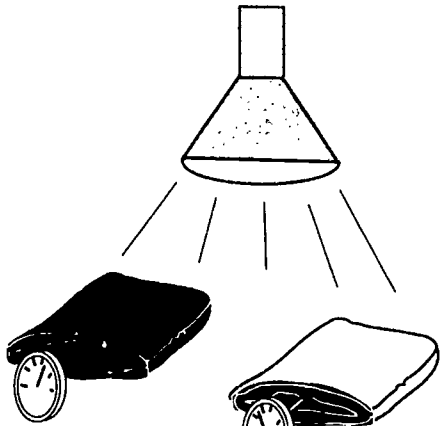
to the suit's backpack, where it runs along a porous metal plate that permits some of it to escape into outer space. The water instantly freezes on the outside of the plate and seals the pores. More water circulates along the back of the plate. Heat in the water is conducted through the metal to melt the ice directly into water vapor. In the process, the circulating water is chilled. The process of freezing and thawing continues constantly at a rate determined by the heat output of the astronaut.

This activity demonstrates how chilled water can keep a metal can from heating up even when exposed to the strong light of a floodlight.

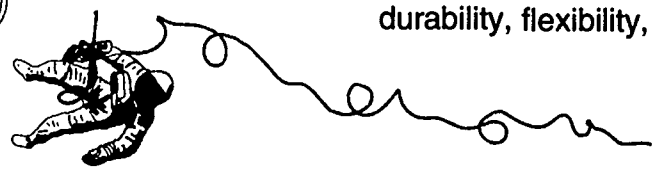
Additional Demonstrations on Cooling:

- Make a sleeve of spandex (stretchable) fabric. Lace the sleeve with plastic aquarium tubing as shown. Circulate cold water through the sleeve with a siphoning action to demonstrate the cooling effects of the Shuttle EMU's liquid cooling-and-vent-garment. Discuss how the water is recycled and rechilled. **Note:** To assist in placing the sleeve on different people, slit the side of the sleeve from one end to the other and attach Velcro strips.
- To help students understand the importance of liquid cooling in the space suit, obtain some tall kitchen plastic garbage bags. Ask each students to place one bare arm inside the bag and wrap the bag snugly around the arm. The bag represents the restraint layer of a space suit. After a minute or two, ask the students to compare how their covered arms feels to the uncovered arms (warm, sweaty, etc.). Why is there a difference? How would they feel if their entire bodies were covered like this?





- Make small bags of various materials to test their insulating properties. Slip a thermometer into each bag and measure the bags' temperature rise when exposed to a heat source such as a floodlight or sunlight. Try using fabrics, paper, aluminum foil, and plastics as well as commercial insulating materials such as rock wool and cellulose. Also experiment with multilayered materials. Compare the bulk and weight of different insulators with their effectiveness. What criteria must spacesuit designers use in evaluating spacesuit insulation? (Weight, bulk, durability, flexibility, flammability.)



Activity 3: Oxygen for Breathing

Topic: Spacesuit life-support

Description: The lung capacity of an average student is determined and related to the oxygen supply carried in the portable life-support system of a spacesuit.

Materials:
Large glass cider jug
Rubber or plastic hose
Basin
Measuring cup
Permanent marking pen
Water
Hydrogen peroxide or other nontoxic disinfectant
Exercise device such as a stationary bike (optional)
Stop watch or clock with a second hand

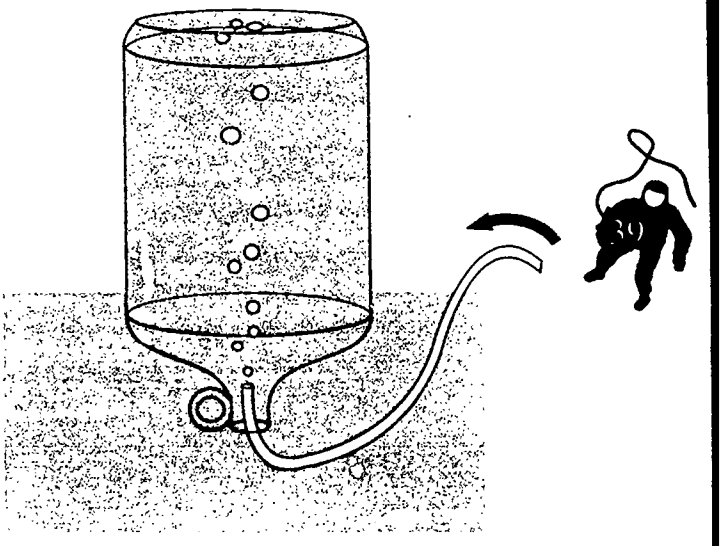
Procedure:

Step 1. Calibrate the glass jug in units of liters. Pour 1 liter of water into the jug and mark the water level on the side of the jug. Add a second liter and again mark the level. Repeat twice more.

Step 2. Completely fill the jug with water and invert it into a basin of water so that air pressure causes the water to remain in the jug. Insert one end of the tube into the jug.

Step 3. Invite several student volunteers, one at a time, to exhale through the tube into the jug. Water will be expelled from the jug. Students should breathe normally when doing this. Count how many breaths it takes to empty the water from the bottle. Also, determine the number of breaths each student takes during one minute. Record the two measurements on a chart under the headings "Breathing Volume" and "Breaths per Minute." **Caution: Be sure to disinfect the end of the tube between student participations.**

Step 4. After all volunteers have participated in the first measurements, run



the experiment again, but this time have each student engage in vigorous exercise for 1 minute before breathing into the tube. Using an exercise bike or running in place should be sufficient to promote heavy breathing. Again measure how many breaths are required to empty the jug. Also measure the number of breaths each student takes during a period of one minute.

Keep a record of these numbers under the headings of "Breathing Volume II" and "Breaths per Minute II."

Step 5. Calculate averages for each of the four columns on the data chart. Use the first set of measurements to determine what volume of air an average student will consume per minute during normal activity. Next, calculate how much air is needed for one hour by that average student under normal activity and under heavy work.

Step 6. Ask the students to calculate how much air would be needed by an average student-astronaut on a six-hour spacewalk. Typically, spacewalks involve both light and heavy exertion.

Discussion:

It is of obvious concern to spacewalking astronauts to have enough oxygen to breathe while they are conducting a mission. They need enough oxygen to complete their assigned tasks and additional oxygen in case of unforeseen problems and emergencies. How much oxygen they carry with them is determined by their oxygen use rate and the time length of their mission. Physically difficult tasks cause astronauts to use oxygen more rapidly than do physically simple tasks.

To provide enough oxygen for spacewalk missions, NASA has had to determine oxygen use rates for different levels of physical activity. Oxygen use is measured rather than air use because it was determined early in the space program that using air for spacewalks would be inefficient because air would require very large holding tanks. Air is approximately 80 percent nitrogen and 20 percent oxygen. By eliminating the nitrogen and providing pure oxygen, much smaller tanks can be used.

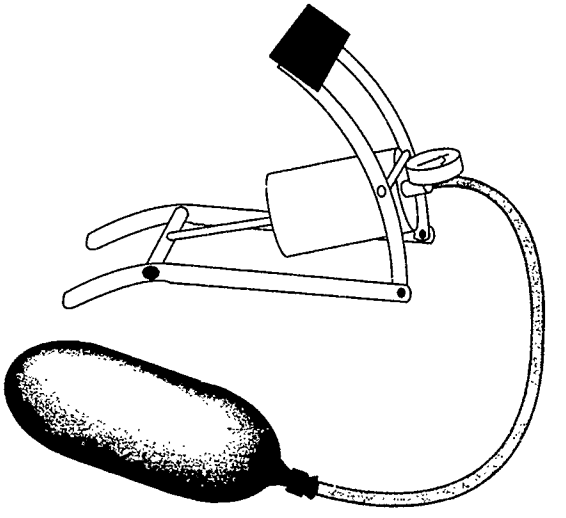
In this activity, students have determined the amount of air an average student breathes during rest and during heavy physical activity. They have calculated how much air would be needed for a six-hour spacewalk. If no one thinks of it, suggest they consider using pure oxygen instead of air. Have your students calculate the volume of pure oxygen that would satisfy the needs of the average student for the six-hour mission and compare this to the quantity of air that would be required for the same mission.

Activity 4: Keeping the Pressure Up

Topic: Spacesuit life-support

Description: How spacesuits maintain a safe pressure environment is demonstrated.

Materials Needed:
Bicycle or automobile foot pump (with pressure gauge)
Gear type of hose clamp (small size—available from hardware store)
Helium quality balloon—30 to 40 cm diameter (several)
Ripstop nylon (about 45 cm from fabric-store bolt)
Thread
Sewing machine
Scissors
Screw driver



Procedure:

Step 1. Use the pattern on the next page to make the nylon restraint layer bag.

Step 2. Slide the pump nozzle entirely into a balloon. The valve should almost touch the other side of the balloon.

Step 3. Slip the hose clamp over the balloon nozzle and tighten it over the air hose.

Step 4. While watching the pressure gauge, pump up the balloon until it breaks. Make a note of the maximum pressure attained.

Step 5. Slip a second balloon over the nozzle as before.

Step 6. Insert the balloon and nozzle into the nylon bag. The nozzle of the balloon should lie just under the nozzle of the bag.

Step 7. Use the hose clamp to seal both the balloon and the bag around the air hose.

Step 8. While watching the pressure gauge, pump up the balloon. Stop pumping when the gauge reaches 35 to 70 kilopascals (5 to 10 lbs per square inch if pump gauge is in English units). Feel the bag.

Note: The balloon can be deflated by loosening the hose clamp.

Discussion:

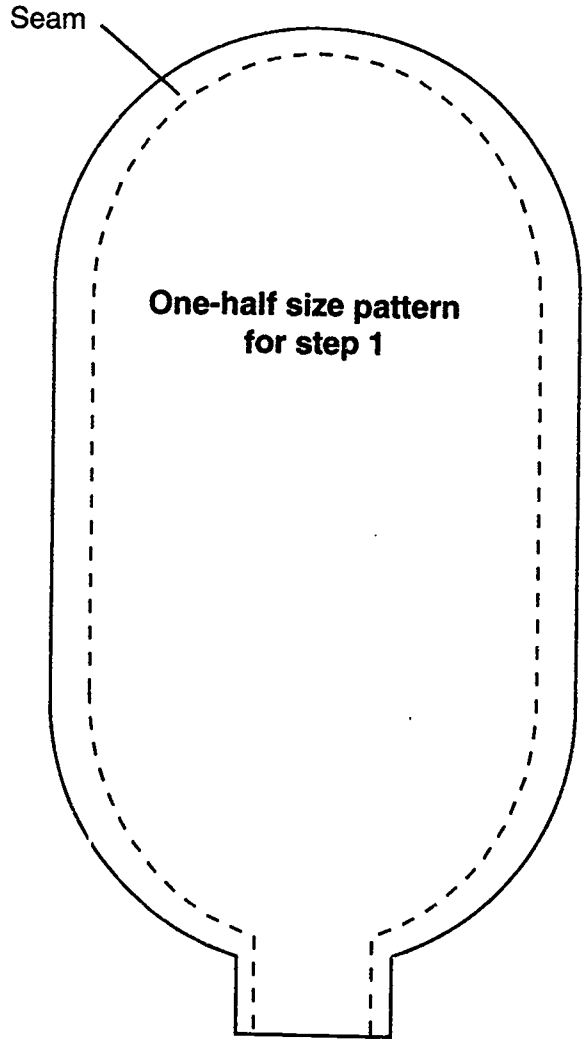
Pressure is essential to human survival in space. Spacesuits provide pressure by enclosing an astronaut inside an airtight bag. A spacesuit is made up of many layers. The pressure-containing portion of the suit is a nylon layer coated on the inside with rubber. The rubber, by itself, acts like a balloon to contain oxygen. This would be fine except that balloons expand when they are pressurized. A spacesuit with just a rubber layer would grow bigger and bigger until it popped. However, the nylon or restraint layer prevents this from happening by permitting expansion to go only so far. Any additional oxygen added to the inside increases the pressure that is exerted on the astronaut wearing the suit.

In this activity, the balloon simulated the rubber layer of a spacesuit, and the nylon bag simulated the restraint layer. When an unrestrained balloon was pumped up, it just increased in size until it popped. Even at the moment of popping, the pressure gauge barely moved. With the restraint layer over the balloon, the balloon could expand only so much, and then additional air pumped inside increased the internal pressure. Thereupon, the bag became very hard and stiff.

The safe operating pressure inside a Shuttle spacesuit is about 29.65 kilopascals. Although this pressure is about one-third that at sea level on Earth, the astronaut wearing the suit experiences no difficulty in breathing, for the gas inside is pure oxygen rather than the approximately 20 percent concentration of oxygen in normal air. Even at the lower pressure, the astronaut takes in more oxygen with each breath inside a spacesuit than on Earth while breathing a normal air mixture.

Sewing Instructions:

Cut out two layers of ripstop nylon according to the pattern and stitch up along the sides indicated. Provide a 1 cm seam allowance. Restitch the seam with a zigzag stitch for reinforcement. Turn the bag inside out. You may wish to hem the open end of the bag to prevent fraying.

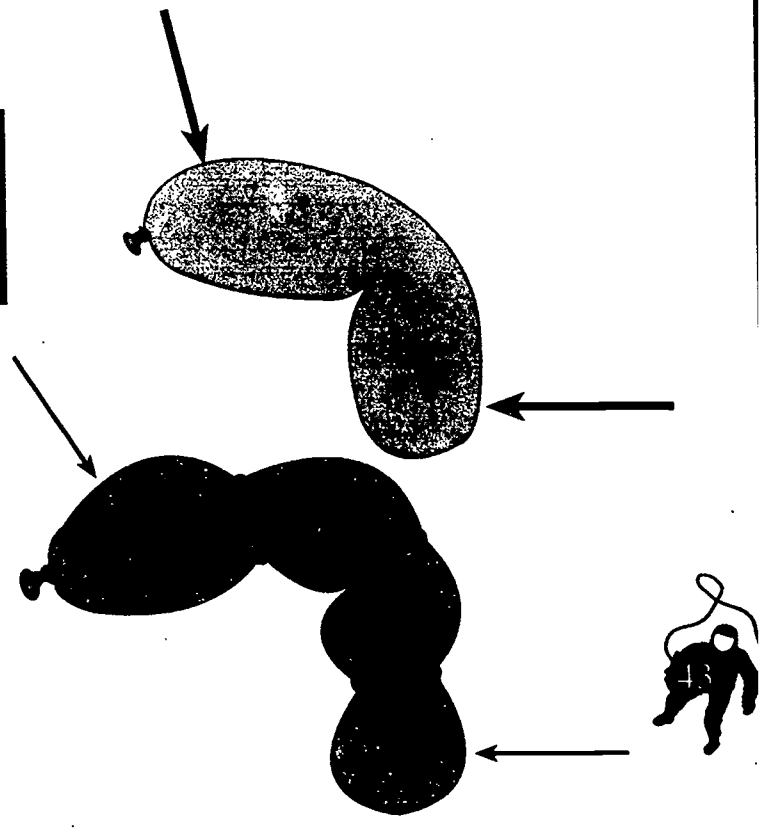


Activity 5: Bending Under Pressure

Topic: Spacesuit mobility

Description: Students compare the ability of inflated balloons to bend in an analogy to the arm of a spacesuit.

Materials Needed:
2 Long balloons
3 Plastic bracelets, metal craft rings, or thick rubber bands



Procedure:

Step 1. Inflate one balloon fully and tie it.

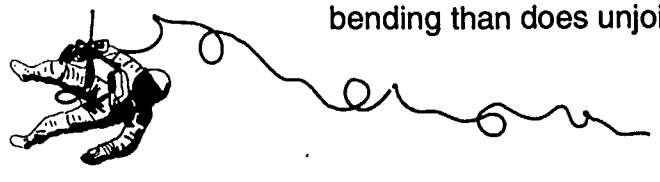
Step 2. Inflate the second balloon, but while it is inflating, slide the bracelets, craft rings, or rubber bands over the balloon so that the balloon looks like sausage links.

Step 3. Ask the students to compare the "bendability" of the two balloons.

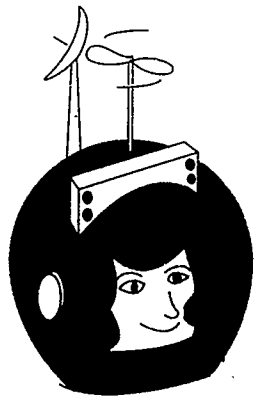
Discussion:

Maintaining proper pressure inside a spacesuit is essential to astronaut survival. A lack of pressure is fatal. Pressure, however, produces its own problems. An inflated spacesuit can be very difficult to bend. In essence, a spacesuit is a balloon with the astronaut inside. The rubber of a balloon keeps in air. But, as pressure inside the balloon builds up, the balloon's walls become stiff and hard to bend. It would be impossible for an astronaut to function effectively in a stiff suit.

Spacesuit designers have learned that strategically placed breaking points (the rings in this demonstration) at appropriate points outside the pressure bladder (the balloon-like layer inside a spacesuit) makes the suit become more bendable. The breaking points help form joints that bend more easily than unjointed materials. The same thing happens with the balloon and rings. Further spacesuit research has determined that there are other techniques for promoting bending. Built-in joints, like ribs on vacuum cleaner hoses, also promote easier bending than does unjointed material.



Activity 6: Getting The Right Fit



Topic: Spacesuit design

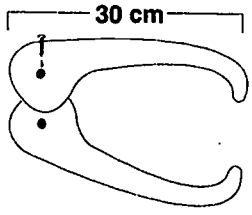
Description: Students design and build space helmets that can be used by anyone in class.

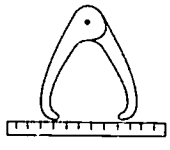
Materials Needed:

Several cloth tape measures (metric)
Metric rulers
Cardboard calipers (see diagram)
Brass paper fasteners
Pencil and paper
Calculator (optional)
Large, round balloons
Papier-mâché paste and newspaper
String
Graph paper
Field-of-view measurement device
Plywood board 60x30 cm
White poster board
Thumbtacks
Marking pen
Protractor

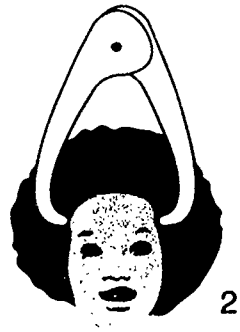
Procedure: Head Measurements

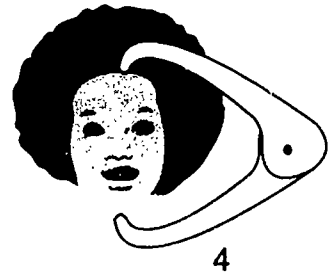
1. Divide the students into groups of three to five.
2. Working as teams, the students should take four separate measurements of each member's head in centimeters, and tally the data. The measurements will be: (1) Head Circumference, (2) Head Breadth, (3) Head Depth, (4) Chin to Top of Head. Refer to the diagram in the next column. Use calipers and cloth tape measures for the actual measuring. Be sure the students check each other's work.





3. After the measurements are taken, the teams should practice calculating averages by averaging the measurements for all members of the team.

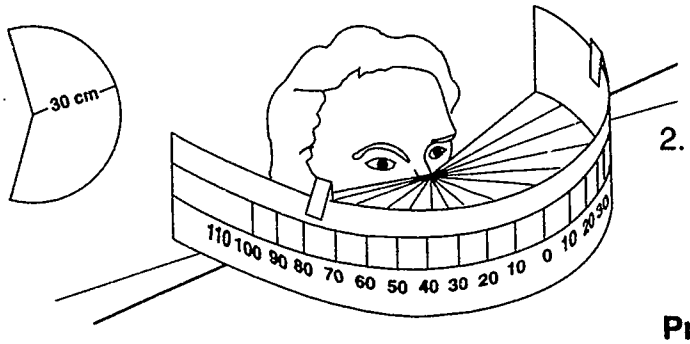




4. Tally the results for all the groups in the class and calculate averages for each measure.

Procedure: Field of View

1. Construct a field-of-view measurement device out of wood and poster board. Cut a partial circle (220 degrees) with a radius of at least 30 cm out of plywood. Refer to the pattern on the next page for



details. Tack or glue a strip of white poster board to the arc. Using a protractor and a marking pen, measure and mark the degrees around the arc as shown in the illustration.

2. Place the device on the edge of a table so that it extends over the edge slightly. Begin measuring the field of view by having a student touch his or her nose to the center of the arc and look straight ahead. Have a second student slide a marker, such as a small strip of folded paper, around the arc. Begin on the right side at the 110-degree mark. The student being tested should say, "Now," when he or she sees the marker out of the corner of the eye. Record the angle of the marker on a data table for the right eye. Repeat for the left eye.
3. Take the same measurements for the other students. When all the data have been collected, calculate the average field of view for all the students.

Procedure: Designing a Space Helmet

1. Working in the same teams as before, have the students draw sketches on graph paper of their ideas for a space helmet that could be worn by anyone in class. The students should determine a scale on the graph paper that will translate into a full-size helmet. In designing the helmet, three considerations must be met. First, it must fit anyone in the class. Second, it must provide adequate visibility. Finally, it must be made as small as possible to reduce its launch weight and make it as comfortable to wear as possible.
2. Students may wish to add special features to their helmet designs such as mounting points for helmet lights and radios.

Procedure: Building a Space Helmet

1. Have each team inflate a large round balloon to serve as a form for making a space helmet. Tie the balloon with a string.
2. Using strips of newspaper and papier mâché paste, cover the balloon except for the nozzle. Put on a thin layer of newspaper and hang the balloon by the string to dry.
3. After the first layer of papier mâché is dry, add more layers until a rigid shell is formed around the balloon. Lights, antennas, and other appendages can be attached to the helmet as the layers are built up.
4. Using a pin, pop the balloon inside the paper mâché shell. According to the design prepared in the earlier activity, cut out a hole for slipping the helmet over the head and a second hole for the eyes.
5. Paint the helmet and add any designs desired.
6. When all helmets are completed, evaluate each one for comfort and utility. Have students try on the helmets and rate them on a scale that the students design. (For example: on a scale of 1 to 5, with 1 the best, how easy is it to put the helmet on?)

Discussion:

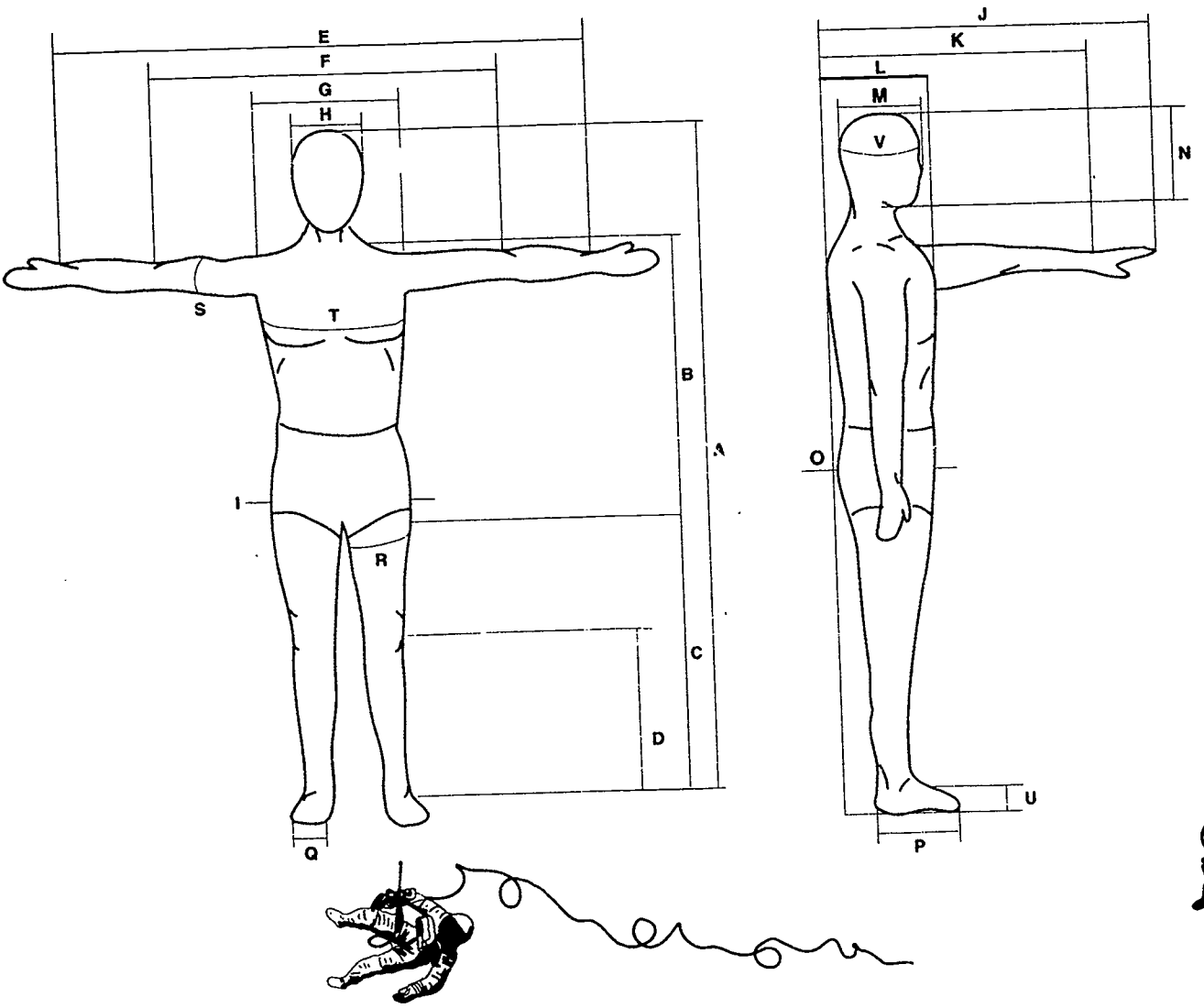
Spacesuit designers have expended great energy to make sure spacesuits fit their wearers properly. It is essential that suit joints line up with the wearer's joints. A mismatched elbow can make it very difficult for the wearer to bend an arm.

To save on spacesuit construction costs, designers have sought to develop common parts that can be worn by the greatest number of people. To do so has required careful evaluation of the human form. Many different people have been measured to determine the ranges of sizes that a spacesuit must fit comfortably. In the present activity only a few head measurements were taken, but in designing complete spacesuits many different measurements are necessary. The dimensions below are based on a spacesuit designed to fit astronauts having this range of measurements.

	Category	Minimum (cm)	Maximum (cm)
A.	Stature*	162.1	187.7
B.	Vertical trunk dimension	64.3	74.4
C.	Knee height	32.3	38.9
D.	Crotch height	74.4	91.9
E.	Wrist to wrist distance	131.6	167.1
F.	Elbow to elbow distance	85.9	106.2
G.	Chest breadth	27.9	36.6
H.	Head breadth	12.7	16.5
I.	Hip breadth	32.3	38.9
J.	Arm reach	80.5	94.2
K.	Shoulder to wrist reach	62.2	73.7
L.	Chest depth	21.3	27.7
M.	Head depth	18.3	21.6
N.	Chin to top of head	21.8	24.4
O.	Hip depth	24.1	29.2
P.	Foot length	21.1	27.4
Q.	Foot width	8.9	10.7
R.	Thigh circumference†	52.1	67.1
S.	Biceps circumference (flexed)	27.4	36.8
T.	Chest circumference	89.2	109.7
U.	Instep	NA	8.3
V.	Head circumference	55.5	60.2

* Stature increases approximately 3 percent over the first three to four days in microgravity. Because almost all the change appears in the spinal column, other dimensions, such as vertical trunk dimension, increase selectively.

† Thigh circumference will significantly decrease during the first day in orbit due to the shift of fluid to the upper torso.



Student Project 2: Spacesuit History

Topic: How spacesuits evolved into their present design

Background Information: The Extravehicular Mobility Unit worn by Space Shuttle astronauts is the result of decades of research and testing. The introductory material in this activity guide provides a brief history of its development.

Research and Writing Assignment: Ask students to research spacesuit history and write reports on specific topics. Students might choose from the following topics:

Project Mercury Spacesuits
Project Gemini Spacesuits
Project Apollo Spacesuits
Skylab Spacesuits
Soviet Cosmonauts' Spacesuits
High-Altitude Aircraft Pressure Suits
Comparison of Spacesuits with Deep Sea Divers' Suits
Spacesuits in Science Fiction Stories and Film

Art Project: Create a mural of the evolution of spacesuit design.

Unit 3

Moving and Working In Space

Activity 1: Spinning Chair

Topic: Moving in space

Description: Students sit, one at a time, on a swivel chair and try to make the chair turn without touching the floor or other furniture with their hands or feet.

Materials Needed:
Swivel stool or desk chair with a good bearing mechanism that permits smooth motion
2 Sandbags made from canvas sacks (about 2 kg each)

Procedure:

Step 1. Ask for a volunteer student to sit on the chair or stool.

Step 2. Instruct the student to make the chair or stool turn in a circle. The student must not touch the floor or anything else except the chair's seat. Stand back and watch.

Step 3. Permit other students to try.

Step 4. Help students out by giving them sandbags to hold in their hands. If no student thinks to toss the bags, suggest that he or she do so at an angle perpendicular to their extended arms (tangential direction).

Caution: Do not use a stool or chair that tips easily. Stand nearby to keep the student from falling. The student should toss the bags gently at first.

Discussion:

Although very difficult, some circular motion may be possible with the chair. Astronauts away from the inside walls of the Space Shuttle orbiter quickly learn that through awkward twisting, it is possible to change

their direction. However, the moment they stop the twisting, the movement they had achieved stops as well. In spite of the movement, center of mass is exactly in the same place as it was before. They learn that to achieve movement from place to place it is necessary to have something to push against to start and something else at the other end to push against to stop.

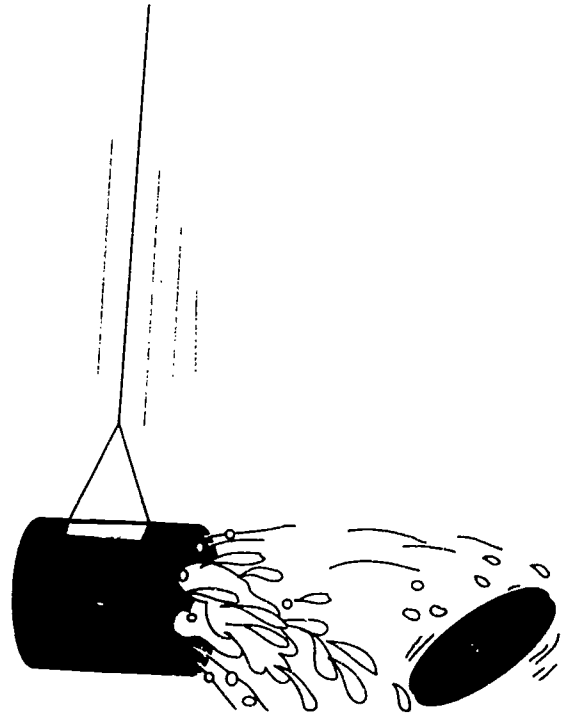
Outside the orbiter, the problem of movement becomes even more difficult. If an astronaut bumps something and is not attached to the orbiter by a tether, the astronaut will simply drift away in the opposite direction, and no amount of twisting and turning will reverse or stop the drift.

In the demonstration, the swivel chair illustrates the manner in which astronauts can change the direction they face but cannot move away without having something to push against. The sandbags, however, do permit real movement through the action-reaction principle stated by English scientist Sir Isaac Newton. The chair continues to spin for a time after the movement stops. Astronauts take advantage of this principle when they wear the Manned Maneuvering Unit while on extravehicular activity. The unit releases compressed nitrogen gas to propel the astronaut along, just as air escaping from a balloon propels it along.

Activity 2: Fizz, Pop!

Topic: Moving in space

Description: Action-reaction demonstration using "antacid power."



Materials Needed:
Plastic 35-mm film canister
Masking tape
String
Water
Effervescent antacid tablet
Eye protection for demonstrator
Towel for mop up

Procedure:

Step 1. Attach a string to the side of a plastic film canister with tape as

shown in the illustration. Suspend the canister from the ceiling, waist-high above the floor.

Step 2. Make a small tape loop and press it to the inside of the film canister cap. Press an effervescent antacid tablet to the tape.

Step 3. Hold the canister upright and fill it halfway with water. Snap the cap, with the tablet, onto the canister snugly.

Step 4. Tip the canister to its side and suspend it from the string. Prevent it from swinging. Stand back and watch. **Note:** Some film canisters don't work as well as others. It is advisable to have a backup in case the first one fizzles.

Caution: Although this activity does not present a significant eye hazard, eye protection is recommended for the demonstrator.

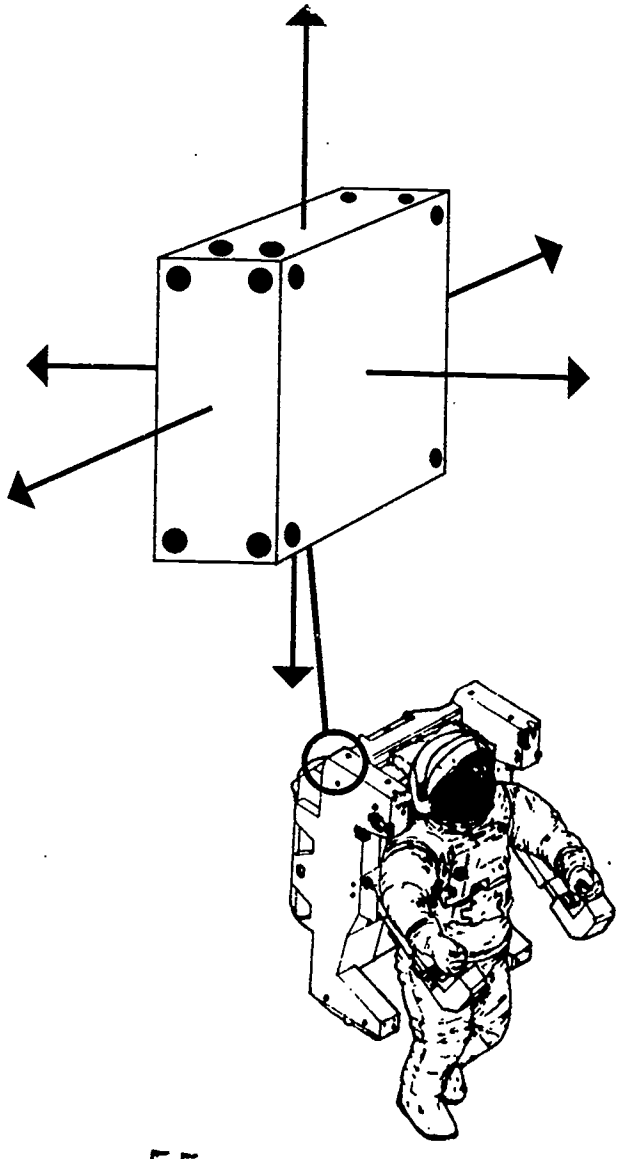
Discussion:

Immediately upon contact with water, the tablet begins effervescing. Because the cap is snapped onto the film canister, gas pressure builds up. Eventually, the cap pops off the end of the canister, releasing the water and gas inside.

The explosive separation of the lid from the canister provides an action force that is balanced with a reaction force that causes the canister to swing the other way. This is a simple demonstration of the action-reaction principle described in Newton's Third Law of Motion.

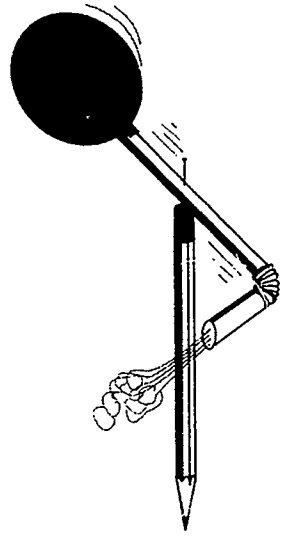
In space, any deviation of a spacecraft's motion from its orbit requires an action-reaction force to be expended. An astronaut on a spacewalk can accomplish the same end by pushing against the spacecraft. The action-reaction force will propel the astronaut in the opposite direction.

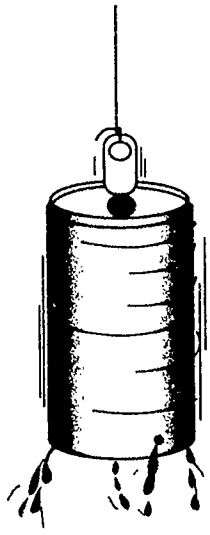
Precise movements in space by spacewalkers can be achieved with the Manned Maneuvering Unit. Although it operates by the same principle as does the popping film canister, the MMU is propelled by compressed nitrogen gas. The MMU is far more controllable than the canister because it has 24 nozzles instead of just the one opening. Shaped like a box with arms, the MMU has nozzles arranged in clusters of three at each corner. Controls on each arm permit sequential firing of pairs of nozzles for precise movements.



Additional Demonstrations on the Action-Reaction Principle:

- Tape a round balloon to the end of a flexible soda straw. Push a pin through the straw into a pencil eraser. Inflate the balloon through the straw and let the air escape.

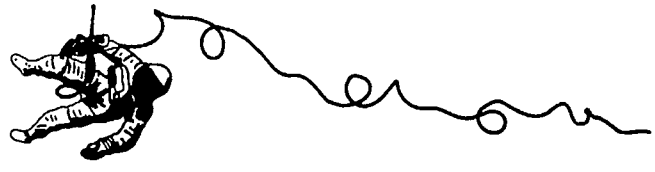




- Make a Hero engine from an aluminum beverage can. Punch angled holes around the base of the can and suspend the can with a piece of string. Fill the can with water by immersing it in a bucket of water. Raise the can out of the water by lifting it with the string. Observe what happens.

The Hero engine was invented by Hero (also called Heron) of Alexandria sometime around the first century B.C. His engine was a sphere connected to a water-filled kettle heated from below. Steam produced by boiling water escaped through two L-shaped tubes and caused the sphere to spin. Remarkably, the Hero engine was considered a novelty and, reportedly, no attempt to harness its power was made at that time.

The principle behind the engine is simple. Steam from the boiling water inside the kettle pressurizes the sphere. The steam rapidly escapes through the tubes, producing an action-reaction force that causes the sphere to spin. The action-reaction principle of the Hero engine is the same that is used to propel airplanes and rockets.



Activity 3: Space Tools

Topic: Space tools

Description: Students practice using tools while wearing heavy gloves that represent the gloves worn by astronauts on spacewalks.

Materials Needed:
Several sets of thick insulated ski gloves or heavy rubber work gloves
Miscellaneous tools and items such as
- Needle-nose pliers
- Socket wrenches
- Small machine screws and nuts
- Lamp cord and plug
- Tinker Toys™ or Legos™
- Perfection™ game

Paper and pencil

Procedure:

Step 1. Instruct students to put on the gloves and begin working with the tools and other items. The gloves represent the stiff, bulky gloves astronauts wear while on spacewalks.

Step 2. Have your students compare the difficulty of doing a particular task such as wiring a lamp cord to a plug, assembling a structure out of construction toys, or writing a message, with and without gloves.

Step 3. Ask your students to try to design tools that could help them do their work in space if they were repairing a satellite.

Discussion:

Spacesuit gloves can be stiff and hard to work in. The gloves worn by Apollo astronauts on the Moon caused much finger fatigue and abrasion during long Moon walks. Designers for the Shuttle spacesuit have placed special emphasis on making pressurized gloves more flexible and easy to wear. This is not a simple task because, when inflated, gloves become stiff just like an inflated balloon. Designers have employed finger joints, metal bands, and lacings to make gloves easier to use.

A second effort is underway to create design tools for use with spacesuit gloves. Even with very flexible spacesuit gloves, small parts and conventional tools can be difficult to manipulate. This activity illustrates the problem of manipulating objects and encourages students to custom-design tools to help spacewalkers do their jobs.

Student Projects 3: EVA Tools and Workstations

Topic: The design of EVA tools and workstations for future space stations

Background Information: When future space stations are constructed, astronauts may have to don their spacesuits and participate in a variety of assembly tasks to bring its parts together. After the stations become operational, EVAs will be necessary for periodic space station maintenance, unscheduled repairs, and to service payloads. Years of EVA experience have shown that even simple jobs, such as turning a screw with a screwdriver, can be very difficult in space if no anchor point is available for the astronaut to brace against. Much research has been invested in the creation of special tools and workstations to make EVA jobs easier. The screwdriver problem is solved with an electric screwdriver that pits the astronaut's inertia against the friction of the screw. Bracing an astronaut for work is solved with workstations—platforms with footholds and tool kits.

Design Project: Ask students to design tools and a workstation that can be used by astronauts assembling a space station. The workstation should have provisions for holding the astronaut in place, holding tool kits, providing adequate lighting, and being moved around the outside of the Space Station to different work sites. The tools should make possible a variety of tasks such as screwing screws, tightening bolts, cutting and splicing wires, and transferring fluids. Students should include in their designs provisions for preventing the tools from drifting off if they slip out of an astronaut's hand and for extending the reach of an astronaut. Have your students illustrate their designs and present oral or written reports on how their tools and workstation will be used. If possible, have them build prototype tools for testing in simulated EVAs.

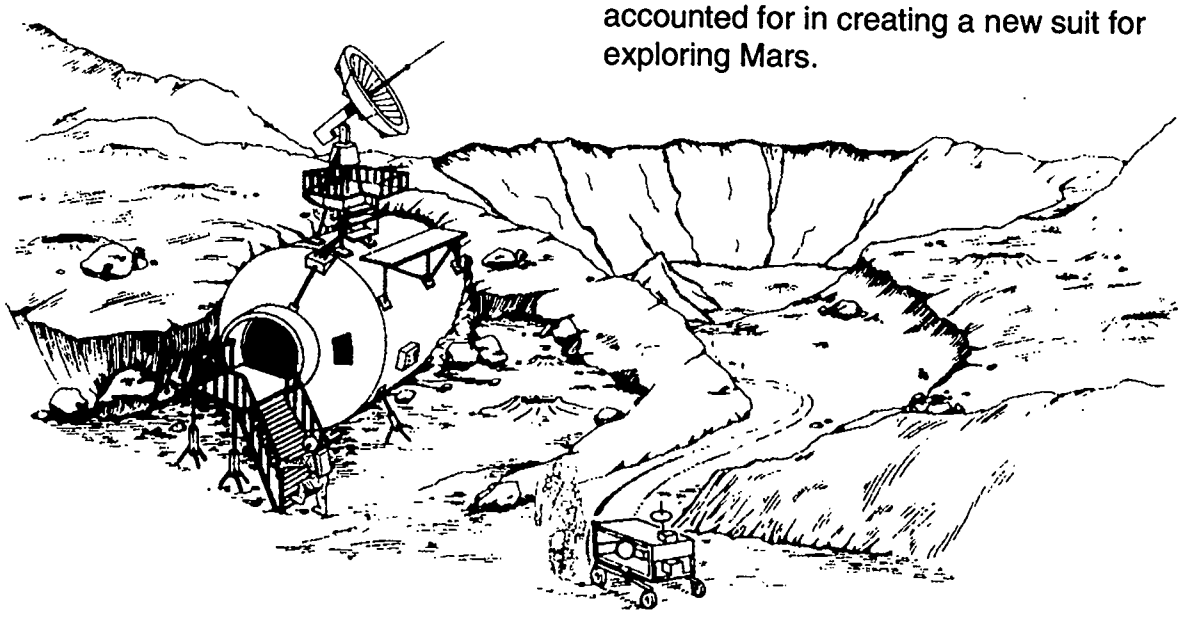
Unit 4

Exploring the Surface of Mars

Group Project: Exploring the Surface of Mars

Objective: This project encourages students to work cooperatively in the development of a spacesuit for the exploration of the surface of Mars and to conduct a simulated EVA on the surface of the planet.

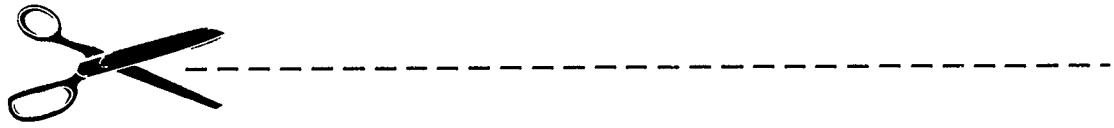
Background Information: Although NASA is not actively planning at this time for crewed space missions to Mars, it is inevitable that rockets will someday carry astronauts to the "red planet." Making this great adventure possible will require the development of many new technologies, including suits for exploring the Martian surface. The Martian environment, although less hostile than that of outer space, is such that a human could not survive there without protection. Although NASA has extensive experience with spacesuits used on the Moon and with suits used on the Space Shuttle, Mars offers new challenges in suit design. Mars has a gravitational pull equal to almost four-tenths that of Earth. This means that new, lightweight structures will be needed to minimize the load the wearer will have to bear. Other factors to be accounted for include: a thin atmosphere that will require a new kind of suit-cooling system, wind-blown Martian dust, and a temperature range that is similar to Earth's. These and many other factors must be accounted for in creating a new suit for exploring Mars.



Teacher's Instructions: Divide your students into working groups that will each work on some aspect of the design of new Martian exploration suits. Each group should select a group leader who will keep track of the activities of the group and report on accomplishments and problems encountered. Also select one or more students as mission managers to see that all groups are working smoothly and on time. Working with the mission managers, develop a schedule for the completion of each group's assigned task. When the suits have been designed and constructed, conduct a simulated mission on the surface of Mars to evaluate the design of the suits.

This activity offers students many opportunities for important lessons in problem solving. For example, one problem is that not everyone can become an astronaut. When the time comes for the actual exploration of Mars, only a tiny fraction of the people on Earth will be able to go. In this activity, only two of the students will wear the suits in the simulation. How should those students be selected? What criteria should be used? What about the people left behind? The important lesson is that everyone's job is important and that teamwork is essential or else the mission would not be possible. The success of the Martian explorers is the success of everyone involved.

Another of the opportunities offered by this activity is the involvement of parents and community members. Parents and community members may be willing to donate suit construction materials and help with the sewing and other tasks of fabrication.



Student Challenge:

You have been assigned to work on one of the teams that will design and test new exploration suits for use on the surface of the planet Mars. You will be given a specific assignment as part of one of several working groups. The goal for all working groups is to bring the components of two prototype suits together so that they can be tested on a simulated Martian mission. Because you will be developing prototype suits for testing on Earth, these suits will not have to be sealed and pressurized.

Working Group Assignments

Working Group 1: Research

What is the environment of Mars like? Go to astronomy books and encyclopedias to find out such important environmental characteristics of Mars as its surface gravity, atmospheric pressure, atmospheric composition, temperature range, and surface composition. Also determine the average size of the students in the class so that the group working on the design and construction will know how large to build the prototype suits. Determine the range and average of your classmates' measurements, including their body height and arm and leg length.
(**Teacher's Note:** Because of sensitivity to weight, measuring waists and chests is not recommended. The prototype suits should be made in a large or extra large size to fit any of the students.)

Working Group 2: Design

What will the Martian suit look like? To answer this question, network with the research working group to find out what the Martian environment is like. The research working group can also tell you how big to make the suits. Contact the life-support working group for details on how the suit will provide a suitable atmosphere, temperature control, and food and water. Furthermore, consider what kinds of tools the Martian explorers are likely to need. Create drawings of the Martian suits and patterns for their construction.

Working Group 3: Life Support

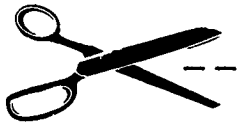
How will you keep the Martian explorers alive and safe in their exploration suits? What will you do to provide air for breathing, provide pressure, and maintain the proper temperature? How will you monitor the medical condition of the explorers? Contact the research working group for details on the environment of Mars. Make drawings of the Mars suit's life-support system and write descriptions of how it will work. Share your plans for life-support with the design working group.

Working Group 4: Construction

From what will you build the Martian exploration suits? Contact the design and life-support working groups for the suit components you must build. Obtain suit patterns from the design working group and collect the necessary construction materials. Build two Mars exploration suits. You may be able to get donations of construction materials from community businesses and the assistance of parents in fabricating the suits.

Working Group 5: Astronaut Selection and Training

Who should be selected to be the astronauts in the simulated mission? Create application forms for interested students who wish to become Martian explorers. Give an application to every interested student. Conduct interviews and select prime and backup crews for the simulated mission. Design a simulated Mars mission that will last 15 minutes. What should the explorers do on Mars? Obtain materials to create a mini-Martian environment in one corner of the classroom. Contact the research working group to learn what the surface of Mars looks like. Develop training activities so that the prime and backup crews can practice what they will do when they test the suit. Create emergency situations of the kind that might be encountered on Mars so that the crews can practice emergency measures. One emergency might be a dust storm.



The Simulation:

Prepare a small test area in one corner of the classroom or in a separate room. Decorate the test area to resemble a portion of the Martian environment. Also prepare a Mission Control center where the test conductors can observe the simulated mission and communicate with the astronauts. If video equipment is available, set up a television camera on a tripod in the test area and stretch a cable to a television monitor in Mission Control. To add additional realism, communicate with the astronauts using walkie-talkies. During the simulation, one very important communication issue will have to be set aside. Communication between Mission Control and the astronauts during the simulation will be instantaneous. During the actual mission to Mars, one-way communication time between Mars and Earth will be at least 20 minutes. If an astronaut asks a question of mission control, 20 minutes will elapse before the message will reach Earth and another 20 minutes will elapse before the answer can be returned. Consequently, the Martian explorers will have to be very well trained to meet every kind of emergency imaginable.

Additional Activities:

- Create a mission patch.
- Publish a project newsletter filled with stories about working group activities, Mars, and other space exploration information.
- Invite parents and community members to observe the simulation.
- Let every student try on the suits and take photos for keepsakes.

Curriculum Application

The chart below is designed to assist teachers in integrating the activities contained in this guide into existing curricula.

Activities	Page Number	Art	Biology	Earth Science	English	Environmental Science	History	Mathematics	Physical Science	Social Studies	Technology Education
		Subjects									
Unit 1: Investigating the Space Environment											
A Coffee Cup Demonstrates Microgravity	26					✓			✓		
Meteoroids and Space Debris	29			✓		✓					✓
Air Pressure Can Crusher	30			✓		✓			✓		
Boiling Water with Ice	31			✓		✓			✓		
Earth is a Spaceship	34	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Unit 2: Dressing for Spacewalking											
Choosing the Right Color	35			✓		✓		✓	✓		✓
Keeping Cool	36			✓		✓		✓	✓		✓
Oxygen for Breathing	39		✓					✓			✓
Keeping the Pressure Up	41								✓		✓
Bending Under Pressure	43								✓		✓
Getting the Right Fit	44	✓	✓					✓			✓
Space Suit History	47	✓			✓		✓		✓		✓
Unit 3: Moving and Working in Space											
Spinning Chair	48								✓		✓
Fizz, Pop!	49								✓		✓
Space Tools	52								✓		✓
EVA Tools and Workstations	53	✓							✓		✓
Unit 4: Exploring the Surface of Mars											
Exploring the Surface of Mars	54	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Glossary

AMU	Astronaut Maneuvering Unit
Apollo	NASA project that landed astronauts on the Moon
CCA	Communications Carrier Assembly
CCC	Contaminant Control Cartridge
DACT	Disposable Absorption and Containment Trunk (female urine-collection system)
DCM	Displays and Control Module
EEH	EMU Electrical Harness
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity; Extravehicular Visor Assembly
Gemini	NASA project that pioneered space flight technologies for spacecraft rendezvous and docking and spacewalking
HHMU	Hand-Held Maneuvering Unit
HUT	Hard Upper Torso
IDB	In-Suit Drink Bag
LCVG	Liquid Cooling-and-Ventilation Garment
Microgravity	The floating-like condition that occurs when objects are in freefall
MMU	Manned Maneuvering Unit
Mercury	The NASA project that launched the first U.S. astronauts into space and demonstrated that humans could live and work in space
PLSS	Primary Life-Support System
RMS	Remote Manipulator System
SCU	Service and Cooling Umbilical
Skylab	First U.S. space station
SOP	Secondary Oxygen Pack
Space Shuttle	Reusable spaceship currently used for all U.S. manned space missions
UCD	Urine Collection Device (male urine-collection system)

References

Allen, J.P. with Martin, M. (1984), *Entering Space, An Astronaut's Odyssey*, Stewart, Tabori & Chang, New York City, NY.

Challenger Center (1991), *Suited for Space Activity Book*, Challenger Center for Space Science Education, Alexandria, VA.

Compton, W. & Bensen, C. (1983), *Living and Working In Space, A History of Skylab*, NASA SP-4208, Scientific and Technical Information Branch, NASA Headquarters, Washington, DC.

Froehlich, W. (1971), *Apollo 14: Science at Fra Mauro*, EP-91, NASA Headquarters, Washington, DC.

Kozloski, L. (1994), *U.S. Space Gear, Outfitting The Astronaut*, Smithsonian Institution Press, Washington, DC.

Machell, R. ed. (1967), *Summary of Gemini Extravehicular Activity*, NASA SP-149, Scientific and Technical Information Division, Office of Technology Utilization, NASA Headquarters, Washington, DC.

Mohler, S.R. & Johnson, B.H. (1971), *Wiley Post, His Winnie Mae, and the World's First Pressure Suit*, Smithsonian Institution Press, Washington, DC.

NASA (1973), *Apollo*, EP-100, NASA Headquarters, Washington, DC.

NASA (1970), *Apollo 12, A New Vista for Lunar Science*, EP-74, NASA Headquarters, Washington, DC.

NASA (1971), *Apollo 15 At Hadley Base*, EP-94, NASA Headquarters, Washington, DC.

NASA (1972), *Apollo 16 At Descartes*, EP-97, NASA Headquarters, Washington, DC.

NASA (1973), *Apollo 17 At Taurus-Littrow*, EP-102, NASA Headquarters, Washington, DC.

NASA (1991), *Go For EVA*, Liftoff to Learning Series. (Videotape), Education Working Group, NASA Johnson Space Center, Houston, TX.

NASA (1987), *The Early Years: Mercury to Apollo-Soyuz*, Information Summaries, PMS 001-A, NASA Kennedy Space Center, FL.

NASA (1970), *The First Lunar Landing As Told by The Astronauts*, EP-73, NASA Headquarters, Washington, DC.

Vogt, G. (1987), *Spacewalking*, Franklin Watts, New York City, NY.

Vogt, G. and Wargo, M. (1992), *Microgravity - A Teacher's Guide With Activities, Secondary Level*, EP-280, NASA Headquarters, Washington, DC.

NASA Educational Resources

NASA Spacelink: An Electronic Information System

NASA Spacelink is a computer information service that individuals may access to receive news about current NASA programs, activities, and other space-related information, including: historical data, current news, lesson plans, classroom activities, and even entire publications. Although it is primarily intended as a resource for teachers, the network is available to anyone with a personal computer and a modem.

Users need a computer, modem, communication software, and a long-distance telephone line to access Spacelink. The Spacelink computer access number is (205) 895-0028. The data word format for direct and Internet access is 8 bits, no parity, and 1 stop bit. It is also available through the Internet, a worldwide computer network connecting a large number of educational institutions and research facilities. Callers with Internet access may reach NASA Spacelink at any of the following addresses:

spacelink.msfc.nasa.gov
xsl.msfc.nasa.gov
192.149.89.61

For more information, contact:
Spacelink Administrator
NASA Marshall Space Flight Center
Mail Code CA21
Huntsville, AL 35812-7015
Phone: (205) 544-6360

NASA Education Satellite Videoconference Series

During the school year, NASA delivers a series of educational programs by satellite to teachers across the country. The content of each videoconference varies, but all cover aeronautics or space science topics of interest to the educational community. NASA program managers, scientists, astronauts, and education specialists are featured presenters. Broadcasts are interactive: a number is flashed across the bottom of the screen, and viewers may call collect to ask questions or to take part in the discussion. The videoconference series is free to registered educational institutions. The programs may be videotaped and copied for later use. To participate, the institution must have a C-band satellite receiving system, teacher release time, and an optional long-distance telephone line for interaction. Arrangements may also be made to receive the satellite signal through the local cable television system. For more information, contact:

Videoconference Coordinator
NASA Teaching From Space Program
Oklahoma State University
300 North Cordell
Stillwater, OK 74078-0422

NASA Television

NASA Television (TV) is the Agency's distribution system for live and taped programs. It offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science.

The educational programming is designed for classrooom use and is aimed at inspiring students to achieve–especially in science, mathematics, and technology. If your school's cable TV system carries NASA TV or if your school has access to a satellite dish, the programs may be downlinked and videotaped. Daily and monthly programming schedules for NASA TV are also available via NASA Spacelink. NASA Television is transmitted on Spacenet 2 (a C-band satellite) on transponder 5, channel 8, 69 degrees West with horizontal polarization, frequency 3880.0 Megahertz, audio on 6.8 megahertz. For more information contact:

NASA Headquarters
Technology and Evaluation Branch
Code FET
Washington, DC 20546-0001

NASA Teacher Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center (TRC) network. TRCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Because each NASA field center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. A list of the centers and the geographic regions they serve starts at the bottom of this page.

Regional Teacher Resource Centers (RTRCs) offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as RTRCs in many states. Teachers may preview, copy, or receive NASA materials at these sites. A complete list of RTRCs is available through CORE.

NASA Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

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The Jet Propulsion Laboratory (JPL) serves inquiries related to space and planetary exploration and other JPL activities.	Dr. Fred Shair Manager, Educational Affairs Office Mail Code 183-900 **Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-8251	NASA Teacher Resource Center JPL Educational Outreach Mail Stop CS-530 **Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-6916
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Grade Level	Application
K-8	Life Sciences, Physical Science, Technology, History, Social Studies

LIFTOFF TO LEARNING

Go For EVA!

Image from the videotape ***Go For EVA!*** *of the Liftoff To Learning Videotape Series*

Go For EVA! is from the *Liftoff to Learning Educational Videotape Series*, which allows students to study science, mathematics, and technology with crewmembers aboard Space Shuttle Flights.

Go For EVA! discusses how spacesuits protect astronauts from the hostile space environment, explains what the components of the spacesuit are, describes how the suit functions, and show what types of work astronauts perform while spacewalking. Actual footage of spacewalks–also known as Extravehicular Activities (EVAs)–illustrate how spacesuits allow astronauts to operate scientific apparatus, assemble equipment and structures, pilot the Manned Maneuvering Unit, take pictures, and service satellites and space hardware.
Length: 13:48

To obtain a copy of the **Go For EVA!** videotape and accompanying Video Resource Guide, or for more information on the *Liftoff to Learning Educational Videotape Series*, contact NASA Central Operation of Resources for Educators (CORE). See page 61.

EDUCATIONAL VIDEOTAPE SERIES

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Educators and scientists at the National Aeronautics and Space Administration would appreciate your taking a few minutes to respond to the statements and questions below. Please return by mail.

SA	-	Strongly Agree
A	-	Agree
D	-	Disagree
SD	-	Strongly Disagree

Exploring the Moon - Activities for Earth and Space Science

1. The teaching guide is easily integrated into the curriculum.	SA	A	D	SD
2. The procedures for the activities have sufficient information and are easily understood.	SA	A	D	SD
3. The illustrations are adequate to explain the procedures and concepts.	SA	A	D	SD
4. Activities effectively demonstrate concepts and are appropriate for the grade level I teach.	SA	A	D	SD

5. a. What features of the guide are particularly helpful in your teaching?

_____

b. What changes would make the guide more effective for you?

_____

6. I teach_____.grade. Subjects _____

7. I used the guide with _____ (number of) students.

Additional comments: _____

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